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This dissertation addresses two topics on market imperfections. First, chapter 2 presents a theoretical model that focuses on problems associated with *informational asymmetry.* The model presents a dynamic signaling game between a monopolist manufacturer and a monopolist retailer, where demand is uncertain and only the retailer is privately informed. This study shows that *informational asymmetry* may provide an explanation of the observation that the retailer may not adjust his/her retail price to new demand conditions. It is shown that both pooling and separating equilibrium exist and pooling equilibrium survives the Cho-Kreps intuitive criterion. Second, chapter 3 provides an empirical analysis of problems associated with *market power* and firm *efficiency*. The analysis investigates whether or not the introduction of competition by trade exposure in 1988 has increased the efficiency of the Korean cigarette industry. An input distance function and corresponding duality to the cost function are employed to specify the estimable system of equations. In order to conduct hypothesis tests about competition and efficiency, a bootstrapping technique is used. It was found that both allocative and technical efficiency increased after 1988

market opening. Moreover, for the entire observation period, raw materials and capital were overutilized compared to labor and raw materials, respectively.

Essays on Market Imperfection

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CONTRIBUTION OF AUTHORS

Dr. Victor J. Tremblay was involved in providing advice and suggestions, and writing of each manuscript. Dr. Steve Polasky was involved in modeling and interpretation of analytical solutions of the first manuscript. Dr. Shawna Grosskopf was involved in providing theoretical backgrounds for the empirical analysis and Dr. John Farrell was involved in writing of the second manuscript.

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ESSAYS ON MARKET IMPERFECTION

1. INTRODUCTION

The dissertation addresses two topics on market imperfections. Chapter 2 presents a theoretical model that focuses on problems associated with *informational asymmetry* between economic agents. Chapter 3 provides an empirical analysis of problems associated with *market power* and firm *efficiency.*

In chapter 2 a dynamic game is developed to analyze problems of *informational asymmetry* and signaling. This game considers strategic interactions between a wholesaler and a retailer where demand is uncertain and only the retailer is privately informed about his/her local demand. This study shows that *informational asymmetries* and strategic interactions between retailers and wholesalers may provide an explanation of the observation that the retail price is not perfectly adjusted to new demand conditions. To explain this behavior requires the development of a game structure that is not yet found in the literature. In our model, the signal-receiver (the wholesaler) moves first by setting the wholesale price while the signal-sender (retailer) is the first mover in a typical signaling model. This problem has not been addressed in the signaling game literature.

In chapter 3 the analysis investigates the relationship between the level of industry competition and firm efficiency in the Korean cigarette market. The Korean cigarette market has been monopolized by a government owned company until 1988 when foreign competition became legal. This produced an oligopolistically competitive market. This chapter uses a *distance function* approach to specify production technology and empirically estimate the impact of increased competition on firm *efficiency* in the Korean cigarette industry. This study is the first study to provide an empirical estimate of firm *efficiency* in the Korean cigarette market. In addition this study helps to understand the optimizing behavior of the Korean bureaucratic organization.

These chapters share topics on *market imperfection.* They both consider frictional factors of market imperfection, the presence of *informational asymmetry* in one case, and *monopoly power* and *inefficiency* in the other. The topics covered in chapter 2 and 3 are further linked by explaining, when the market is imperfect, how the market outcome and the behavior of individual economic agents depart from what the theory of perfect competition suggests. In chapter 2 the presence of *informational asymmetry* between the retailer and the wholesaler and the existence of pooling equilibrium explain stickiness of retail price adjustment and *market power* in chapter 3 makes firms operate more inefficiently. Finally, chapter 4 contains summary and conclusions.

2. DEMAND UNCERTAINTY AND TRADE SIGNALING BETWEEN A MANUFACTURER AND A RETAILER

2.1 Introduction

When demand for products is uncertain, retailers might have to set their retail price and choose how much inventory to hold only based upon their expectation of demand which occurs prior to demand arrival. After demand is realized, however, it is often observed that retail prices are slow to react to new demand conditions. In some markets there could be constraints on the ability of retailers to adjust their prices. For instance, it might take time for demand information to reach retailers or price information takes time to convey to customers. Even in markets with few constraints, instantaneous retail prices adjustment is not a general phenomenon. Recent studies have presented empirical evidence supporting the significant staggering in price changes (Lach and Tsiddon (1992, 1996), Tommasi (1993)).

The most common explanation for cross-sectional price dispersion and staggering in price changes builds on the existence of price adjustment costs (menu costs) and not perfect correlation among the demand shocks at different firms. Sheshinski and Weiss (1977, 1983) show an optimal pricing rule (S, s) for a monopolistically competitive firm. [1] Agurregabiria (1999) combines the

[1] Under the (S, s) pricing rule, a nominal price does not change if real price moves between an upper bound, S and a lower bound, s.

classical inventory model[2] and pricing models with menu costs[3] to allow for joint price and inventory decision with lump-sum ordering costs and shows that fixed ordering costs play a very important role in the dynamics of retail prices.

Theories about resale price maintenance, RPM have also attempted to address the sluggishness of retail prices. Deneckere, Marvel and Peck (1996) offer one explanation of why a manufacturer would prefer not to have its products sold by discounters. They show RPM could increase the manufacturer's wholesale demand and profits under demand uncertainty.

However, these models assume the retailers are monopolistically competitive and price-takers of wholesale price. Consequently, they do not consider possible strategic interaction between the wholesaler and the retailer. Albaek and Overgaad (1991) analyze the vertical relation between the manufacturer and a retailer in a signaling game where the manufacturer is privately informed about the demand. Vincent (1998) considers a signaling game between a seller and a buyer in general where the buyer is privately informed about demand and the buyer can possibly a retailer. In none of these signaling games does the retailer's inventory stock play an important role in the strategic interaction. Lariviere and Porteus (1995) show that the inventory stock plays a role through which information about demand is acquired. But in most cases it appears to be unrealistic to assume that an individual retailer's inventory stock is not observable to either wholesaler or consumers.

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[2] See Scarf (1959) and Blinder (1981).

In this paper we present a model that considers a strategic interaction between a monopolist manufacturer and a monopolist retailer where the retailer is privately informed about his local demand. The monopolist and the retailer play a signaling game in this model. In the model presented in this paper, the signal receiver (manufacturer) is the first mover who sets the wholesale price for his/her products while signal sender moves first by sending signals of his private information in a typical signaling game. Dynamic signaling games in which the informed player has a large strategy space are typically plagued by a large set of multiple equilibria. What happens to the set of equilibria in a different structure of the signaling game where the receiver is the first mover?

The following section presents a formal model. Section 2.3 discusses the equilibrium of the model. In section 2.3.1 we solve the dynamic game assuming complete information. The analysis focuses on the role of the unobservable retailer's inventory stock as a strategic bargaining power. Section 2.3.2 presents the equilibrium concept of the signaling game under incomplete information, and in section 2.4, we show the existence of both pooling and separating equilibrium through an example and examine the features of these equilibrium. In Contrast to the traditional signaling game, in this environment where the signal receiver moves first, it is shown that the equlibria is a subset of a large set of equilibria that typical signaling game generates. Finally section 2.5 concludes and discusses limitations and possible extensions of the model.

[3] See Sheshinski and Weiss (1977, 1983, 1992).

2.2 The Model

A manufacturer sells a good to a retailer who in turn sells to consumers. The retailer is assumed to know demand condition while the manufacturer does not. There are two periods, t = 1, 2 in the game. The manufacturer and the retailer have a common discount factor δ. In each period, the manufacturer sets a wholesale price, first and the retailer chooses the amount of the good to purchase and sets the retail price. Finally, consumers decide how much to purchase given the retail price. The retailer can have a positive amount of inventory stock if the retailer purchases more from the manufacturer than it sells to consumers. Consumer demand may be high or low. The demand curve takes a simple linear form $D = \theta^S - p_t$, where D is the quantity demanded by consumers. p_t is retail price in period t, and θ^S is a demand parameter where the superscript, S denotes a state of nature, $S = H, L$. The manufacturer and the retailer seek to maximize their total discounted expected profits. The profit of the manufacturer is given by

$$\Pi^A = r_1 q_1 + \delta r_2 q_2,$$

where r_t is the wholesale price and q_t is the wholesale quantity sold to the retailer in period t. Superscript A and B denote the manufacturer and the retailer, respectively. For simplicity, we assume the manufacturer can produce the good at zero cost. The retailer's profit is

$$\Pi^B = p_1 s_1 - r_1 q_1 + \delta[p_2 s_2 - r_2 q_2],$$

where s_t is the retail sales to consumers in period t. If $q_1 > s_1$, then the retailer's inventory is $x = q_1 - s_1$. The retailer can also choose first period order quantity q_1 and retail price p_1 such that there is excess demand in the local market. Having excess demand in one period does not affect demand in the following period.[4] Since the game ends in period 2, the optimal p_2 and q_2 should not lead to excess demand or supply in period 2, so that $s_2 = \theta^S - p_2$ and $q_2 = s_2 - x$.

2.3 Equilibrium

2.3.1 Complete Information

To understand the basic game structure, it is helpful to solve the game by backward induction assuming complete information. In complete information the retailer always choose p_1 and q_1 so that there is no excess demand in period 1, i.e., $s_1 = \theta^S - p_1$. Therefore we have following identities:

***Identity* 1.** $q_1 - x = \theta^S - p_2$

2. $q_2 + x = \theta^S - p_2$

First, using the identity **2**, the retailer's problem in period 2 can be written as

$$Max\, p_2(\theta^S - p_2) - r_2(\theta^S - p_2 - x)$$

[4] An example is a soft drink market where a consumer will likely substitute another type of drink rather than demand more of the same type of drink at a later date if unable to purchase it at present.

From the first order conditions we obtain p_2 as the following.

$$p_2 = \frac{1}{2}(\theta^S + r_2) \tag{1}$$

Also, using the identity *2*, we can solve for q_2 as

$$q_2 = \frac{1}{2}(\theta^S - r_2) - x \tag{2}$$

Equation (2) implies that if r_2 is relatively high to the inventory stock such that $(\theta^S - r_2)/2 \leq x$, then the retailer need not order any quantity in the second period. Second, by substituting for q_2 in equation (2) into the manufacturer's second period profit, the manufacturer's problem in period 2 is expressed as

$$\underset{\{r_2\}}{Max}\, r_2(\frac{1}{2}\theta^S - \frac{1}{2}r_2 - x)$$

The optimal r_2 is

$$r_2 = \frac{1}{2}\theta^S - x \tag{3}$$

Note that if $x \geq \theta^S/2$, then $r_2 = 0$. This implies that since r_2 cannot be negative, the retailer has no incentive to hold his inventory stock more than $\theta^S/2$. Now consider the optimizing problems in period 1. Both agents are to maximize total discounted expected profits. First, the retailer's problem assuming $r_2 \geq 0, q_2 \geq 0$ in period 1 is

$$Max\ p_1(\theta - p_1) - r_1(\theta - p_1 + x) + \delta[p_2(\theta - p_2) - r_2(\theta - p_2 - x)]$$

From the first order conditions it is straightforward to obtain the following solutions.

$$p_1 = \frac{1}{2}\theta^S + \frac{1}{2}r_1 \tag{4}$$

$$x = \frac{1}{2}\theta^S - \frac{2r_1}{3\delta} \qquad \text{if } r_1 < 3\theta\delta/4$$

$$= 0 \qquad \text{if } r_1 \geq 3\theta\delta/4 \tag{5}$$

Note that if $r_1 \geq 3\theta\delta/4$, $x = 0$ and so, r_2 in equation (3) becomes $r_2 = \frac{1}{2}\theta^S$. The optimal q_1 is calculated by using identity **1** and equation (4) and (5) as

$$q_1 = \theta^S - \frac{1}{2}r_1 - \frac{2}{3\delta}r_1 \qquad \text{if } r_1 < 3\theta\delta/4$$

$$= \frac{1}{2}\theta^S - \frac{1}{2}r_1 \qquad \text{if } r_1 \geq 3\theta\delta/4 \tag{6}$$

For future reference, we can also express r_2 as a function of p_1 and q_1.

$$r_2 = \frac{3}{2}\theta^S - (p_1 + q_1) \qquad \text{if } r_1 < 3\theta\delta/4$$

$$= \frac{1}{2}\theta^S \qquad \text{if } r_1 \geq 3\theta\delta/4 \ \ (\text{since } p_1 + q_1 = \theta^S) \tag{7}$$

Second, using equation (2) and (7), we can rewrite the manufacturer's problem as a function of r_1 as

$$Max\ r_1(\theta^S - \frac{r_1}{2} - \frac{2r_1}{3\delta}) + \frac{2r_1^2}{9\delta}$$

The optimal r_1 is obtained from first order condition as

$$r_1 = (\frac{9\delta}{9\delta + 8})\theta^S \tag{8}$$

For positive inventory x, it must be satisfied that $r_1 < 3\delta\theta^S/4$ as in equation (5). If $\delta > 4/9$, the r_1 in equation (8) is less than $3\delta\theta^S/4$. Therefore, if $\delta > 4/9$, the optimal inventory stock is positive given the manufacturer's optimal r_1. Therefore, it can be concluded that the retailer chooses an order that yields a positive amount of inventory stock for a reasonable range of discount rates. The retailer does this for a strategic reason to increase his bargaining power and lower the second period wholesale price. This result occurs even though the magnitude of local demand is commonly known.

2.3.2 Incomplete Information

Now, suppose that only the retailer knows local consumer demand. We assume the manufacturer observes only the retail price and order quantity sold to the manufacturer in each period but not the retailer's inventory amount. The manufacturer-retailer interaction becomes a signaling game where the retailer strategically uses his private information with choosing p_1 and q_1 as signals of demand. In this game, two types of equilibrium are analyzed: pooling and separating equilibrium.

2.3.2.1 Pooling equilibrium

In a typical signaling game the privately informed player sends a signal first. Differently, in our model the uninformed agent, the manufacturer moves first setting the wholesale price in the first period. Obviously, the first period choice of the manufacturer's wholesale price should be the one maximizing his total profit over two periods. However, how to set r_1 appears to be a difficult problem. Therefore, now, let us consider a sub game which consists of steps after initial wholesale price, r_1 is determined. We examine two types of equilibrum, pooling and separating, given the first period wholesale price, r_1.

In pooling equilibrium, the retailer wants to hide information about consumer demand by choosing the same combination of (p_1^P, q_1^P) regardless of whether demand is high or low. The superscript p denotes pooling strategy. Pooling equilibrium fail to exist if beliefs for non-pooling p_1 and q_1 are high type. To describe a pooling equilibrium, first, we need to specify the manufacturer's belief, $\mu(H| p_1, q_1)$, where $\mu(H| p_1, q_1)$ is the probability of the high type when he observes p_1 and q_1. The off-path equilibrium of the manufacturer is that the probability of the high type $\mu(H \mid p_1, q_1) = 1$ for any observable $(p_1, q_1) \neq (p_1^P, q_1^P)$. Simply, if the manufacturer's belief is

$$
\begin{aligned}
\text{(i)} \quad \mu(H| p_1, q_1) &= 1 \qquad \text{for } (p_1, q_1) \neq (p_1^P, q_1^P) \\
&= \lambda \qquad \text{for } (p_1, q_1) = (p_1^P, q_1^P),
\end{aligned}
$$

where superscript denotes pooling strategy. Then the manufacturer's strategy is

$$\text{(ii)}\quad r_2(p_1, q_1) = r_2^H \qquad \text{for } (p_1, q_1) \neq (p_1^P, q_1^P)$$

$$= r_2^P \qquad \text{for } (p_1, q_1) = (p_1^P, q_1^P)$$

In a pooling equilibrium the manufacturer cannot update his prior belief after observing (p_1^P, q_1^P) since he initially believes that the retailer will choose (p_1^P, q_1^P) no matter whether demand is high or low. Thereby, he sets corresponding wholesale price, r_2^P which maximizes the manufacturer's second period expected profit, $E\Pi_2^A(r_2^P)$. However, even if r_2^P is argmax of $E\Pi_2^A(r_2^P)$, the manufacturer might want to charge not the wholesale price r_2^P but r_2^H to the retailer in the second period. This occurs when the profit from charging r_2^H is greater than charging r_2^P.[5] In this case the second period wholesale price will always be r_2^H regardless of the retailer's type and the each type of retailer will choose its optimal (p_1, q_1) corresponding to the r_2^H, respaectively. Therefore, there is no incentive for the retailer to hide information by choosing (p_1^P, q_1^P). Consequently, in this case, a pooling equilibrium cannot exist. For the purpose of analyzing pooling equilibrium, the rest of discussion in this paper will concentrate only the case where the manufacturer charges r_2^P in the second period. Therefore the following additional condition must be satisfied.

$$E\Pi_2^A(r_2^P) = r_2^P(\lambda q_2^H(r_2^P) + (1-\lambda)q_2^L(r_2^P)) \geq E\Pi_2^A(r_2^H) = r_2^H(\lambda q_2^H(r_2^H) + (1-\lambda)q_2^L(r_2^H))$$

[5] First, if r_2^P is such that $(\theta^L - r_2^P)/2 < x^L$, the low type retailer's second period order quantity from t q_2^L is zero and only the high type's order quantity q_2^H is positive. In this case, because the manufacturer only profits when $S = H$, charging r_2^H rather than r_2^P is more profitable: the manufacturer's expected profit in period 2 $E\Pi_2^A(r_2^H) = r_2^H \lambda q_2^H > E\Pi_2^A(r_2^P) = r_2^P \lambda q_2^H$. Second, even if q_2^L is positive given r_2^P, the manufacturer might still charge r_2^H, when manufacturer's expected second period profit by charging r_2^H is greater than that by charging r_2^P: $E\Pi_2^A(r_2^H) = r_2^H \lambda q_2^H > E\Pi_2^A(r_2^P) = r_2^P[\lambda q_2^H + (1-\lambda)\, q_2^H]$.

where $E\Pi_2^A(r_2^P)$ and $E\Pi_2^A(r_2^H)$ are the manufacturer's second period profit by charging r_2^P and r_2^H respectively.

When the manufacturer charges r_2^P given (p_1^P, q_1^P), the profit of the retailer in equilibrium is

$$\Pi_B(p_1^P, q_1^P \mid r_2^P) = p_1^P q_1^P - r_1 q_1^P + \delta[p_2(\theta^S - p_2) - r_2^P q_2]$$

Note that unlike the complete information case, the first period sales quantity s_1 is not necessarily greater or equal to $\theta^S - p_1^P$ but might be less than $\theta^S - p_1^P$. That is, it is possible to have excess demand. In summary, conditions for a pooling equilibrium to exist are

Condition* 1.** ***i. $r_1 \in \textbf{\textit{argmax}}\ \Pi^A$

ii. $r_2^P \in \textbf{\textit{argmax}}\ \Pi_2^A$

iii. $E\Pi_2^A(r_2^P) \geq E\Pi_2^A(r_2^H)$

iv. $(p_1^P, q_1^P) \in \textbf{\textit{argmax}}\ \Pi^B$

iv.i $\Pi^B(p_1^P, q_1^P \mid r_2^P, \theta^H, r_1) \geq \Pi^B(p_1, q_1 \mid r_2^H, \theta^H, r_1)$

iv.ii $\Pi^B(p_1^P, q_1^P \mid r_2^P, \theta^L, r_1) \geq \Pi^B(p_1, q_1 \mid r_2^H, \theta^L, r_1)$

The conditions, ***iv.i*** and ***iv.ii***, imply that for both types of demand, the retailer should not have any incentive to deviate from the equilibrium. In other words, the profit of the retailer in pooling equilibrium should be greater or equal to the maximum profit when deviating from (p_1^P, q_1^P). The wholesale price in the second period r_2^P can be written as a function of (p_1^P, q_1^P) and this may take different functional form depending on the manufacturer's prior belief about (p_1^P, q_1^P).[6] Given an initial first period wholesale price r_1, if the wholesale price in the second period r_2^P is substituted into the profit function of the retailer, it can be also expressed as a function of (p_1^P, q_1^P) and r_1. Figure 2.1 provides the retailer's profit function and pooling equilibrium condition, ***iv.i*** and ***iv.ii***. In Figure 2.1 (a) and (b) the $r_1 \in [r_1^{H0}, r_1^{H1}]$ satisfies the condition ***iv.i*** and the $r_1 \in [r_1^{L0}, r_1^{L1}]$ satisfies the condition ***iv.ii***. In Figure 1 (a), within the range of $r_1 \in [r_1^{H0}, r_1^{H1}]$, the retailer's second period profit curve, $\Pi^B(p_1^P, q_1^P | r_2^P, \theta^H, r_1)$, lies above the curve, $\Pi^B(p_1, q_1 | r_2^H, \theta^H, r_1)$. Similarly, in Figure 1 (b), the curve, $\Pi^B(p_1^P, q_1^P | r_2^P, \theta^L, r_1)$, lies above the curve, $\Pi^B(p_1, q_1 | r_2^H, \theta^L, r_1)$, for the range, $r_1 \in [r_1^{L0}, r_1^{L1}]$. Thus, the range r_1 of that satisfies both conditions, ***iv.i*** and ***iv.ii*** is the intersection of $[r_1^{H0}, r_1^{H1}]$ and $[r_1^{L0}, r_1^{L1}]$. Provided that $r_1^{L0} < r_1^{H0} < r_1^{L1} < r_1^{H1}$, the range of for pooling equilibrium is $[r_1^{H0}, r_1^{L1}]$. For r_1 out of this range, pooling equilibrium is not possible and the only possible equilibrium is separating. Even if there exists a range of r_1 that satisfies both conditions, ***iv.i*** and ***iv.ii***, the pooling equilibrium may not be sustainable. This occurs when the manufacturer's maximum expected profit from charging r_1 out of the range, $[r_1^{H0}, r_1^{L1}]$ is greater than the maximum expected profit in pooling equilibrium given the range of $r_1 \in [r_1^{H0}, r_1^{L1}]$.

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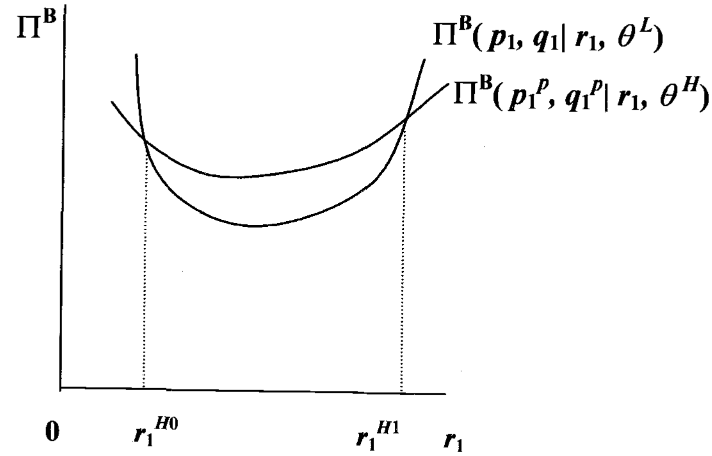
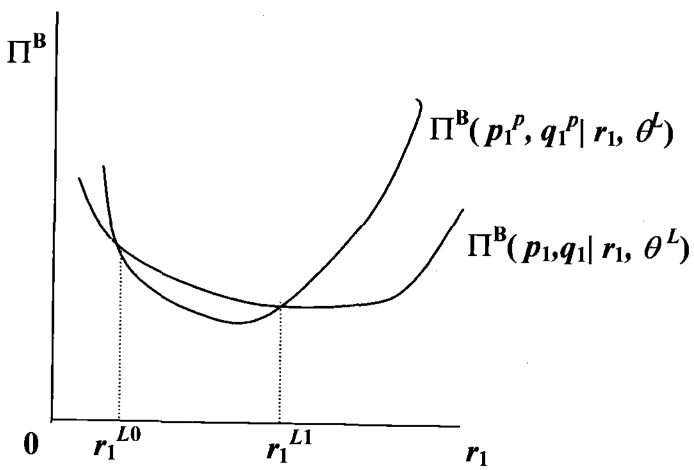
[6] This is because variables such as optimal solutions, x, r_2, p_2, and q_2 are not differentiable in some parameter regimes. For example, the function $r_2 = 3\theta^S/2 - (p_1^P + q_1^P)$ is kinked at $p_1^P + q_1^P = \theta^S$ because $r_2 = 3\theta^S/2 - (p_1^P + q_1^P)$ if $p_1^P + q_1^P \geq \theta^S$ but 0 otherwise.

Figure 2.1 The Range of the First Period Wholesale Price For Pooling Equilibrium



(a) High Type



(b) Low type

2.3.2.2 Separating Equilibrium

In a separating equilibrium, the retailer reveals his type. To describe the separating equilibrium the manufacturer's belief needs to be specified. One belief that fulfills conditions for separating equilibrium is

$$\text{(i)}\quad \mu(L \mid p_1, q_1) = 1 \qquad \text{for } (p_1, q_1) = (p_1^L, q_1^L)$$
$$= 0 \qquad \text{otherwise}$$

The manufacturer's strategy is

$$\text{(ii)}\quad r_2(p_1, q_1) = r_2^L \qquad \text{for } (p_1, q_1) = (p_1^L, q_1^L)$$
$$= r_2^H \qquad \text{otherwise}$$

Then the retailer's best response must be

$$\text{(iii)}\quad (p_1, q_1 \mid r_2^L) = (p_1^L, q_1^L) \text{ and } (p_1, q_1 \mid r_2^H) = (p_1^H, q_1^H)$$

In summary the conditions for a separating equilibrium are

Condition 2. ***i.*** $r_1 \in \textbf{\textit{argmax}}\ \Pi^A$

ii. $r_2^S \in \textbf{\textit{argmax}}\ \Pi_2^A$

iii. $(p_1^S, q_1^S \mid r_2^S, \theta^S) \in \textbf{\textit{argmax}}\ \Pi^B(r_2^S, \theta^S)$

iii.i $\Pi^B(p_1^L, q_1^L \mid r_2^L, \theta^L, r_1) \geq \Pi^B(p_1^H, q_1^H \mid r_2^H, \theta^L, r_1)$

iii.ii $\Pi^B(p_1^H, q_1^H \mid r_2^H, \theta^H, r_1) \geq \Pi^B(p_1^L, q_1^L \mid r_2^L, \theta^H, r_1)$

Generally, bad type (high demand type in our model) has an incentive to mimic the other type. The condition ***iii.i*** and ***iii.ii*** implies that for both types of demand, the retailer should not have any incentive to mimic the other type in the equilibrium. In other words, the profit of the retailer from revealing his type in a separating equilibrium should be greater or equal to the maximum profit from mimicking the other type. The retailer's profit from revealing is

$$\Pi^B(p_1^S, q_1^S \mid r_2^S) = p_1^S(\theta^S - p_1^S) - r_1 q_1^S + \delta[p_2(\theta^S - p_2) - r_2^S q_2]$$

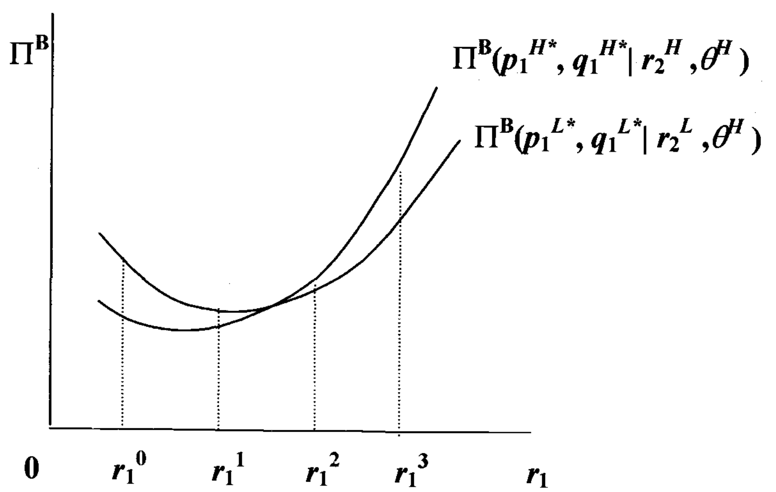
The retailer's profit from mimicking is

$$\Pi^B(p_1^T, q_1^T \mid r_2^T, \theta^S) = p_1^T q_1^T - r_1 q_1^T + \delta[p_2(\theta^S - p_2) - r_2^T q_2],$$

where $S \neq T$. Any pair of (p_1, q_1) that satisfies the above conditions, ***iii***, ***iii.i***, and ***iii.ii*** can be possibly a separating equilibrium. Therefore there exists an area of equilibrium pair of (p_1, q_1) in a (p_1, q_1) space. A particular pair of (p_1, q_1) as an equilibrium depends on the monopolist's prior belief about the separating equilibrium. Similar to pooling equilibrium, the profits from mimicking and revealing are finally functions of the initial r_1. We should notice that if the profit from revealing is greater than from mimicking, there is no incentive for the retailer to mimic the other type. In this no envy[7] case each type of retailer will fully reveal his type, and so, the equilibrium is identical to the complete information case. As depicted in Figure 2.2, since the high type retailer's profit from mimicking lies above the profit from revealing for the range of $r_1 \in [r_1^0, r_1^2]$, it is envy case. It is no envy case in the range of $r_1 \in [r_1^2, r_1^3]$.

[7] In no-envy case, the high type retailer can achieve the highest payoff because his best response to r_2^H yields higher profit than to r_2^H such that $\Pi^B(p_1^H, q_1^H \mid r_2^H, \theta^H) > \Pi^B(p_1^L, q_1^L \mid r_2^L, \theta^H)$

Figure 2.2 The Range of the First Period Wholesale Price For Separating Equilibrium



where (p_1^{S*}, q_1^{S*}) is the complete information solution (fully revealing), $S = H, L$.

2.3.2.3 The Intuitive Criterion

We are interested in whether pooling equilibrium survives under the intuitive criterion (Cho and Kreps 1987).[8] Consider the following conditions.

$$\textit{Condition } 3.\ \textit{i.}\ \Pi_B^{HP}(p_1^P, q_1^P | r_2^P) > \Pi_B^{H}(p_1, q_1 | r_2^L)$$

$$\textit{ii.}\ \Pi_B^{LP}(p_1^P, q_1^P | r_2^P) < \Pi_B^{L}(p_1, q_1 | r_2^L)$$

Define (p_1', q_1') to be an area of (p_1, q_1) that satisfies the condition ***i*** and ***ii*** in p_1 and q_1 space. Suppose there exists (p_1', q_1'). Then, choices of (p_1, q_1) such that $(p_1, q_1) \in (p_1', q_1')$ are equilibrium-dominated for the retailer facing high type demand, because even the lowest wholesale price in the second period yields lower profit to the retailer than the profit under pooling equilibrium. However, these choices are not equilibrium-dominated for the low-demand type retailer. If such a choice convinces the manufacturer that the consumer demand is low, then the manufacturer will offer low wholesale price in the second period, which will make the low-demand type retailer better off than pooling equilibrium. Thus, since the low type retailer has an incentive to deviate from pooling equilibrium, the Cho - Kreps intuitive criterion is not satisfied in this case.

[8] If the information set following a message m_j is off the equilibrium path and equilibrium dominated for the type S, then the receiver's belief μ $(S \mid m_j)$ should place zero probability on S. See Cho and Kreps (1987).

2.4 Example

It can be shown that a pooling and a separating equilibrium exist by considering a simple example. Suppose that $\theta^H = \mathbf{1}$, $\theta^L = \mathbf{1/2}$, $\lambda = \mathbf{0.1}$ and $\delta = \mathbf{1}$.

2.4.1 Pooling Equilibrium

Suppose that the manufacturer's initial belief $(p_1^P, q_1^P) = (0.445, 0.105)$. The manufacturer knows each type of retailer's inventory amount. Since $p_1^P + q_1^P = 0.55 > \theta^L = 0.5$, the low type retailer's inventory x^L is positive: $x^L = q_1^P - (\theta^L - p_1^P)$. The low type's second period order quantity is $q_2^L = \theta^L - p_2^L - x^L$. If we substitute $p_2^L = (\theta^L + r_2^P)/2$ and $x^L = q_1^P - (\theta^L - p_1^P)$ into q_2^L, we can calculate q_2^L as

$$q_2^L = \frac{3}{2}\theta^L - \frac{1}{2}r_2^P - (p_1^P + q_1^P)$$

However, the manufacturer expects the high type retailer has some sales in period 1 but no inventory stock since $q_1^P + p_1^P = 0.55 < \theta^H = 1$. Therefore, the order quantity of the high type retailer in period 2 is $q_2^H = \theta^H - p_2$. Using $p_2^H = (\theta^H + r_2^P)/2$ we obtain

$$q_2^H = (\theta^H - r_2^P)/2$$

The manufacturer's expected second period profit $r_2^P[\lambda(q_2^H) + (1-\lambda)(q_2^L)]$ is then

$$E\Pi_2^A = r_2^P[\lambda(\frac{\theta^H - r_2^P}{2}) + (1-\lambda)(\frac{3\theta^L}{2} - \frac{r_2^P}{2} - (p_1^P + q_1^P))],$$

From the first order condition, the optimal r_2^P is

$$r_2^P = \lambda(\frac{\theta^H}{2}) + (1-\lambda)(\frac{3\theta^L}{2} - (p_1^P + q_1^P))$$

From above formula we can obtain r_2^P, p_2^H, p_2^L, q_2^H, and q_2^L in this example as followings.

$r_2^P = 0.1(1/2) + 0.9(0.75 - 0.55) = 0.23$

$p_2^H(r_2^P) = \theta^H/2 + r_2^P/2 = (1 + 0.23)/2 = 0.615$

$q_2^H = (1 - 0.23)/2 = 0.385$

$p_2^L = (1/2 + 0.23)/2 = 0.365$

$q_2^L = 3/2 - (0.23)/2 - 0.55 = 0.085$

The condition **1.** ***ii*** is satisfied so that the manufacturer charges r_2^P as discussed in previous section (see Appendix B.1).

2.4.2.1 Profits of the Retailer

Now, let's consider the retailer's profit from pooling strategy and the maximum profit from deviation.

Profit of the high type

Pooling: $\Pi^{BH}(p_1^P, q_1^P \mid \theta^H, r_2^P) = 0.19495 - 0.105r_1$ (see Appendix B.2.a)

If the retailer deviates from pooling strategy, then he faces r_2^H. So, the maximum profit is identical to the profit fully revealing his type under complete information (see Appendix A).

Deviation: $\Pi^{BH}(p_1^H, q_1^H \mid \theta^H, r_2^H) = 7r_1^2/12 - r_1 + 1/2$ if $r_1 < 0.75$

$= 5/16 - r_1/2 + r_1^2/4$ if $0.75 \leq r_1 < 1$

(see Appendix B.2.b)

Profit of the low type

Pooling: $\Pi^{BH}(p_1^P, q_1^P \mid \theta^L, r_2^P) = 0.0542 - 0.105r_1$ (see Appendix B.2.b)

Deviation: $\Pi^{BH}(p_1^L, q_1^L \mid \theta^L, r_2^H) = 1/2(1/4 - r_1^2) - r_1(1/2 - r_1)$ if $r_1 < \theta^L$

$= 0$ if $r_1 \geq \theta^L$

(see Appendix B.2.c)

The range of r_1 that satisfies condition **1. *iv.i*, 1. *iv.ii*, 2. *iii.i***, and **2. *iii.ii*** is

(1) 0.51109 ≤ r_1 ≤ 0.5162 (see Appendix B.3)

If the manufacturer sets the wholesale price in the first period r_1 within the range in (1), then pooling equilibrium exists since p_1^P, q_1^P, r_2^P, p_2^S, and q_2^S are mutual best responses to each other given the manufacturer's prior belief $(p_1^P, q_1^P) = (0.445, 0.105)$. For r_1 out of this range, pooling equilibrium cannot be possible and if there exists an equilibrium, the only possible equilibrium is separating.

Now consider the manufacturer's expected profit in pooling equilibrium (see Appendix B.4) and the manufacturer's expected profit in separating equilibrium for each range of r_1. For each different range of r_1, possible sets of separating equilibrium are analyzed in Appendix C. Also, the manufacturer's expected profits are calculated in Appendix D. For the time being, if we present the result of analysis, the Profits in both pooling and separating equilibrium are

$$\text{Pooling} \quad : \quad Max\,\Pi^A(r_1, r_2^P \mid p_1^P, q_1^P) = r_1 q_1^P + r_2^P[\lambda q_2^H + (1-\lambda) q_2^L]$$

$$= 0.08065 \qquad (\text{when } r_1 = 0.5162)$$

$$\text{Separating:} \quad Max\,\Pi^A(r_1, r_2^S \mid p_1^S, q_1^S) = 0.08007, \qquad \text{if } r_1 \leq 0.375$$

$$= 0.07344, \qquad \text{if } 0.375 < r_1 \leq 0.5$$

$$= 0.05438, \qquad \text{if } 0.5 r_1 \leq 0.75$$

$$= 0.05, \qquad \text{if } r_1 \geq 0.75$$

If the manufacturer has prior belief $(p_1^P, q_1^P) = (0.445, 0.105)$ and accordingly charges r_1 within the range, $0.51109 \leq r_1 \leq 0.5162$, then a pooling equilibrium is possible. The manufacturer's maximum expected profit in pooling equilibrium is 0.08065. Out of the range, the manufacturer knows pooling equilibrium does not exist, so, the only possible equilibrium is separating. When r_1 is out of range $0.51109 \leq r_1 \leq 0.5162$, the maximum expected profit of the manufacturer in separating equilibrium is 0.08007. Therefore, given the manufacturer's prior belief charging $r_1 = 0.5162$ is more profitable to the manufacturer and a pooling equilibrium exists in this example.

2.4.2.2 The Intuitive Criterion

To examine the intuitive criterion we need to consider the second period wholesale price for the low type, r_2^L. We can express r_2^L with p_1 and q_1 instead of inventory stock x. In this circumstance because the manufacturer believes that the retailer is the low type, r_2^L would be followings.

$$r_2^L = \frac{1}{2}\theta^L \qquad \text{If } p_1 + q_1 < \theta^L$$

$$r_2^L = \frac{3}{2}\theta^L - (p_1 + q_1) \qquad \text{If } \theta^L \leq p_1 + q_1$$

From the manufacturer's perspective, the optimal $p_1 + q_1$ is greater than θ^H. However, if $p_1 + q_1 > 3\theta^L/2$, it means $x > \theta^L/2$, and then this will obviously tell the manufacturer that the retailer is not the low type because the low type retailer will never have $x > \theta^L/2$. Therefore, the restriction for solutions is $p_1 + q_1 \leq 3\theta^L/2$. Now, let's consider the minimum of $\Pi_B^H(p_1, q_1| r_2^L)$. If $q_1 = 0$, then the second period wholesale price r_2^L takes the highest value, $3\theta^L/2$. Consequently, $p_2^H(r_2^L)$ is $(\theta^H + \frac{1}{2}\theta^L) = (1 + 0.25)/2 = 0.625$ and $q_2^H(r_2^L) = \theta^H - p_2^H(r_2^L) = 0.375$.

This will lead the zero profit in period 1 and the minimum second period profit to the retailer. Thus, the minimized profit of the retailer is

$$Min\ \{\Pi_B^H(p_1, q_1| r_2^L)\} = [(p_2^H(r_2^L) - r_2^L)(\ \theta^H - p_2^H(r_2^L))]$$

$$= [(0.625 - 0.25)(0.375)] = 0.146025$$

Suppose $\Pi_B^{HP}(p_1^{\mathrm{P}}, q_1^{\mathrm{P}}| r_2^{\mathrm{P}}) < \min \{\Pi_B^{H}(p_1, q_1| r_2^{\mathrm{L}})\}$. Then we can say that there is not any combination of (p_1, q_1) that satisfies the condition **3. *i*.** Even if there are some combinations of(p_1, q_1) that satisfy the condition **3. *ii*,** it is guaranteed that there is no (p_1, q_1) that satisfies the condition **3. *i*** and **3. *ii*** simultaneously. Therefore, this is a sufficient condition for satisfying the intuitive criterion. To satisfy the condition the following must be true.

$$\Pi_B^{HP}(p_1^{\mathrm{P}}, q_1^{\mathrm{P}}| r_2^{\mathrm{P}}) = 0.19495 - 0.105r_1 < \min \{\Pi_B^{H}(p_1, q_1| r_2^{\mathrm{L}})\} = 0.146025$$

The range of r_1 that satisfies the above inequality is

$$\textbf{(2) } \boldsymbol{r_1 > 0.46595}$$

Conclusively, if r_1 is in this range, the pooling equilibrium satisfies the intuitive criterion. Since the range if r_1 for existence of pooling equilibrium in section 2.4.1 is in the above range (2), it can be concluded that, in this example, the pooling equilibrium also survives the Cho – Kreps intuitive criterion.

2.4.2 Separating Equilibrium

Suppose the manufacture believes the retailer will employ a separating strategy. Depending on different regimes of initial r_1, the possible separating equilibrium are (see Appedix C):

(1) If $r_1 > 3\delta\theta^H/4$:

No envy case: separating equilibrium is that each type chooses the complete information solution fully revealing his type.

(2) If $\theta^L \leq r_1 \leq 3\theta^H/4$:

If $0.5127 \leq r_1 \leq 0.75$ it is envy case (there is an incentive for mimicking). However, there is no way to make the high type not to mimic the low type even though the high type retailer has an incentive to mimic the low type. So, the high always mimic the low type and there is only an unique pooling equilibrium with $(p_1^P, q_1^P) = (p_1^L, q_1^L)$. Therefore, there is no separating equilibrium in this case. If $0.5 \leq r_1 < 0.5127$, then in separating equilibrium the each type reveals it's type by choosing the solution under complete information.

(3) If $3\theta^L/4 \leq r_1 < \theta^L$:

Separating equilibrium is that each type chooses the complete information solution fully revealing his type.

(4) If $r_1 < 3\theta^L/4$:

It is no envy case and separating equilibrium is identical to the solution under complete information. As we saw in previous section, the manufacturer will obtain the maximum expected profit 0.08007 by charging r_1 = 0.29118 (see Appendix D). Given the manufacturer's first period wholesale price $r_1 = 0.29118$, the retailer's optimal choices are:

$$p_1^L = (\theta^L + r_1)/2 = 0.39559$$

$$p_1^H = (\theta^H + r_1)/2 = 0.64559$$

$$q_1^L = \theta^L - 7r_1/6 = 0.16029$$

$$q_1^H = \theta^H - 7r_1/6 = 0.66029$$

Thus, equilibrium is defined as

$$(r_1,\ p_1^L,\ p_1^H,\ q_1^L,\ q_1^H) = (0.29118,\ 0.39559,\ 0.64559,\ 0.16029,\ 0.66029)$$

Therefore, in this example, we showed that there exit both pooling and separating equilibrium.

2.5 Conclusions

This paper presents a model that considers strategic interactions between a monopolist manufacturer and a retailer in a dynamic signaling game when the retailer's inventory stock can play a role in bargaining power.

First, in the game assuming complete information, the retailer chooses a wholesale order quantity that yields a positive amount of inventory stock in equilibrium. Unlike the classical inventory models, the reason for a positive amount of inventory is not because of demand uncertainty but because of the strategic reason to increase his/her bargaining power in second period.

Second, in the signaling game under incomplete information it is shown that both pooling and separating equilibrium exist. We also show existence of a pooling equilibrium that survives the Cho – Kreps intuitive criterion. In addition, it is found that a dynamic signaling game, where the signal receiver is the first mover, can eliminate a subset of a large set of equilibria that a general signaling game typically produces.

Finally, it is possible that in a pooling equilibrium a change in retail price over periods is smaller than that of an equilibrium under complete information. Therefore, without menu costs or ordering costs, staggering in price is partially explained by a strategic interaction between wholesalers and retailers under asymmetric information.

In this study we focus on a game between a monopolist wholesaler and a monopolist retailer. Future study may explore a signaling game in an oligopolistic market where retailers and wholesalers have oligopoly powers. Possible extensions may include a multiple periods or infinite horizon signaling game.

3. COMPETITION AND EFFICIENCY IN THE KOREAN CIGARETTE MARKET: A DISTANCE FUNCTION APPROACH

3.1 Introduction

For many years, the Korean governmental corporation had a monopoly in the sale of cigarettes in Korea. In 1948 a government agency, the Monopoly Bureau of Ministry of Finance was established as the sole distributor of cigarettes and red ginseng. Regarding the cigarette business, it had monopsony power in the tobacco leaf market and, at the same time, monopoly power in the sale of cigarettes. In April 1952 the Monopoly Bureau reorganized into the Office of Monopoly. In 1987 it was transformed into a government-invested institution. In 1997 its legal status was changed to a joint-stock company. Now the Korean cigarette company (Korea Tobacco and Ginseng Corporation) plans to privatize the corporation by the year 2000.

The most remarkable change in the Korean cigarette market, however, was that the domestic market was opened for foreign companies in 1987 and it was completed in 1988. With this change, the market structure of the Korean cigarette industry is likely to have become more competitive.

Before 1987, the main sources of X-inefficiency[1] were, first, lack of competition and second, bureaucracy. The level of competition in the Korean cigarette market has increased since 1988 due to market liberalization. It is argued that competition is expected to make firms more efficient than they would be under less competition (Leibenstein 1969, Clarkson 1972). There is some evidence that being forced to compete reduces costs and raises efficiency. For example, Crandall (1989) and Shin and Ying (1993) found that increased competition resulted in significant productivity gains for firms in the U.S. telephone industry. On the other hand, it is also agreed that the impact of competition on the efficiency of the industry is not always positive but depends on many factors including the characteristics of the industry. Grosskopf et al. (1993) conclude that the banks operating under competition became more efficient after the major market concentration by consolidation and mergers in the U.S. banking industry in 1991. Wilson and Jadlow (1982) obtained empirical findings that support the hypothesis that, hospitals with less competition are more efficient. Now, given structural change of the market in Korean cigarette industry in 1988, one might question whether there has been an improvement in the level of efficiency of the Korean cigarette firm due to increased competition.

Bureaucracy still remains because the Korean cigarette company has not privatized yet. An organization such as a non-profit organization or a government enterprise may suffer from inefficient allocation of resources. Since the objectives of managers in those organizations may involve their utilities as well as the profits, their behavior may not be consistent with simple cost minimization.

[1] The existence of X-efficiency implies that firms do not always introduce technical changes when available and profitable (Leibenstein, H., 1969).

Niskanen (1971) first developed a theory of the supply of public goods in a bureaucracy which predicts that production will exceed the socially optimal size. Mique and Belanger (1974) have extended the Niskanen model by proposing that managers prefer large staffs. Williamson (1964) offers a similar model where a utility maximizing director will operate a firm to his own interests by acquiring larger staffs. De Alessi (1969) proposes a model where public utility managers will exhibit a bias toward capital-intensive budget. Thus competition-efficiency relationship and bureaucratic inefficiency are empirical issues that cannot be assumed but need to be tested on a case-by-case basis.

In this study, we investigate whether or not the introduction of competition by trade exposure has increased the technical and/or allocative efficiency of the Korean cigarette company. In order to analyze efficiency change, we first follow a distance function approach to model production technology. The distance function is appropriate to describe multi-output technology since outputs include two types of cigarettes, filter and non-filter type. Second, we apply the duality from Shephard's lemma to derive shadow prices of inputs and specify input price equations. A behavioral cost is explicitly included in the input price equations.[2] The behavioral cost is obtained from using shadow input prices in the cost equation instead of actual input prices. A system of equations is, then, constructed with the distance function and input price equations. The system is jointly estimated using annual data on the Korean cigarette market from 1965 to 1996. Then we compare the ratio of shadow prices

[2] This 'behavioral cost' is analogous to the 'shadow cost' in Atkinson and Harvorsen (1986).

to the ratio of observed prices to obtain the Korean firm's allocative efficiency for each observation. Third, given observed residuals, we calculate the expected value of non-negative error that represents technical inefficiency by decomposing the error term into two random variables in the manner of stochastic frontier estimation. Finally, we use a bootstrapping technology to test hypotheses about competition and efficiency in Korean cigarette market. The paper is organized as follows. In section 3.2 an inefficiency model with input allocation is introduced. In section 3.3 the theory of distance function and duality is briefly reviewed. Section 3.4 contains the stochastic model specification and data description. In section 3.5 empirical results are discussed. Section 3.6 concludes the paper.

3.2 The Inefficiency Model with Input Allocation

The standard competitive input allocation for a firm's cost minimization problem is that marginal rates of technical substitution equal factor price ratios. In reality, however, this is not necessarily true for various reasons. Literature on the effects of rate of return regulation on efficiency tells us that relative price efficiency (marginal rates of technical substitutions equated to factor price ratios) does not exist in the regulated industry. When input choices are not flexible due to a long-term contract, or complete information about input prices is not available, firms may also suffer from input misallocation. As seen in the previous section, bureaucracy can be a source of this type of inefficiency. If a non-optimal input allocation occurs, this implies a firm chooses input in such a manner as to minimize not the actual cost but the shadow cost.[3]

For an example, let's consider a bureaucratic organization model. It is assumed that bureaucrats maximize a utility which is a function of output and inputs of a production process. Grosskopf and Hayes (1993) formalize the general problem as:

$$\max \Lambda = u(y,x) + \mu(\overline{R} - \sum_i w_i x_i) + \delta(1 - D(y,x)),$$

where

$y = (y_1, \ldots, y_m)$, is the vector of outputs;

$x = (x_1, \ldots, x_n)$, is the vector of inputs;

$w = (w_1, \ldots, w_n)$, is the vector of input prices;

$\overline{R}$ = revenue or budget, assumed to be fixed;

and

$D(y, x)$ = multi-output technology [4]

The first-order conditions yield the allocation of inputs which maximizes the utility:

$$\frac{\partial D(y,x)/\partial x_i}{\partial D(y,x)/\partial x_j} = \frac{w_i - (\partial U(y,x)/\partial x_i)/\mu}{w_j - (\partial U(y,x)/\partial x_j)/\mu} \tag{1}$$

[3] Also see Atkinson and Harvorsen (1986).

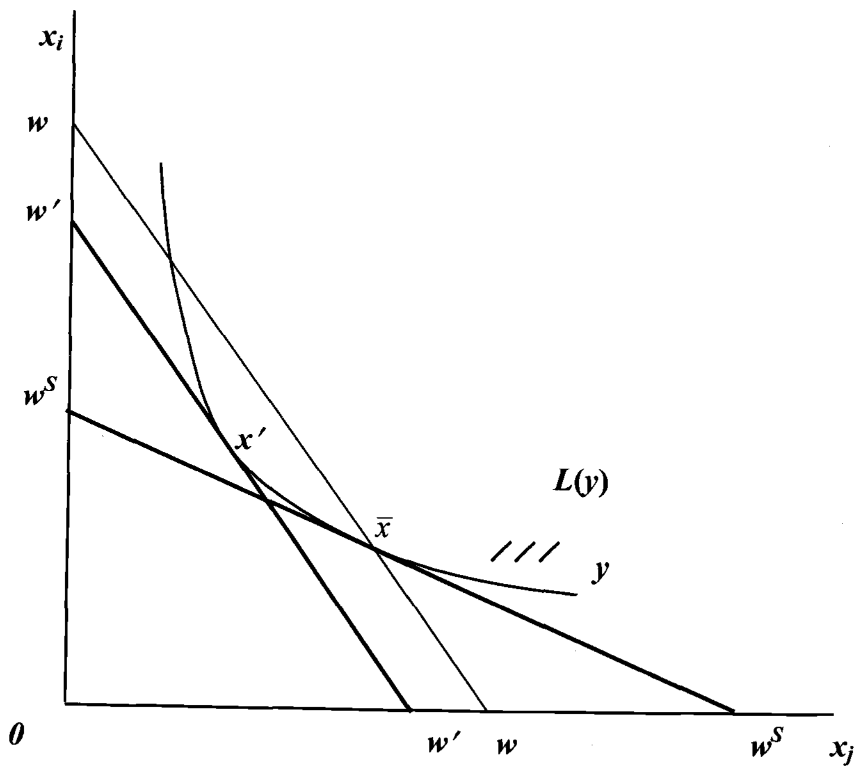
[4] $D(\cdot)$ is the input distance function, a multiple output representation of technology, allowing for joint production. $D(\cdot)$ is discussed in more detail in Section 3.3.

Equation (1) can be rewritten as

$$\frac{\partial D(y,x)/\partial x_i}{\partial D(y,x)/\partial x_j} = \frac{w_i^S}{w_j^S} \neq \frac{w_i}{w_j}, \tag{2}$$

where w_i^S is the ith shadow input price. If w_i^S/w_j^S is less than w_i/w_j, the relative shadow price of x_i is lower than the actual price ratio and this implies the bureaucrat overutilizes that input relative to observed input price. This is illustrated in Figure 3.1, where input x_i is relatively overutilized.

Figure 3.1 Input Choice Bundle and Allocative Efficiency



The observed relative price of the input bundle $\bar{x}$ is given by the absolute value of the slope of the line ww. The relative shadow prices for the input vector $\bar{x}$ is given by the absolute value of the slope of the line $w^S w^S$. Note that the isoquant is tangent to the line $w'w'$ at x', illustrating the fact that cost is not minimized at $\bar{x}$ with ww. Allocative inefficiency is captured by the deviation between w_i^S/w_j^S and w_i/w_j.

3.3 The Distance Function and Duality

3.3.1 The Distance Function

The input distance function is a mapping from the set of input vectors, $x \in \Re_+^n$, $x = \{x_1, x_2, \ldots, x_n\}$ and output vectors, $y \in \Re_+^m$, $y = \{y_1, y_2, \ldots, y_m\}$ into the real line. Formally this function, $D_I(y, x)$ is defined as

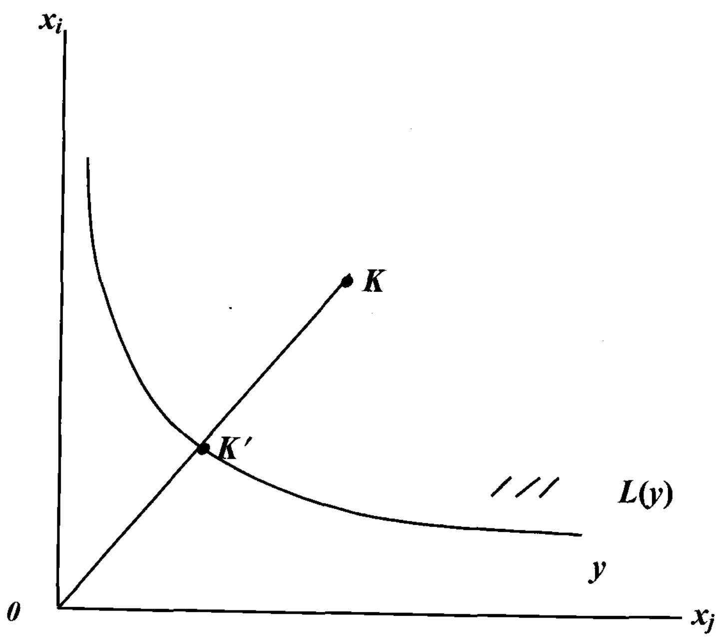
$$D_I(y, x) = \max\{\theta \mid (x/\theta) \in L(y)\}, \qquad (3)$$

where

$$L(y) = \{x \mid x \text{ can produce } y\} \qquad (4)$$

The input distance function seeks the maximum possible radial contraction of the observed input bundle x which allows production of the observed output bundle y. Figure 3.1 helps to understand the distance function. Observation K employs the input bundle (x_i^K, x_j^K) to produce output level y^K (which may be a vector). In this example, the value of the distance function for observation K is OK/OK'. Since the technical efficiency for this observation is OK'/OK, i.e. Farrell technical efficiency is the reciprocal of the distance function. Thus, technical efficiency is $1/D_I(y^K, x^K) = OK'/OK$. $D_I(y, x) = 1$ if and only if the input bundle is an element of the isoquant of $L(y)$, and for any x and y such that $x \in L(y)$, $D_I(y, x) \geq 1$. The input distance function provides a complete description of technology with minimal structure. The distance function satisfies fairly general regularity properties (see Fare and Grosskopf, 1990). It is homogeneous of degree one in inputs, concave in inputs, convex in outputs, non-decreasing in inputs and non-increasing in outputs. The distance function can easily model a multiple output technology and has the advantage of being dual to the cost function which we use to identify allocative efficiency.

Figure 3.2 Input Distance Function: $D(y^K, x^K) = OK/OK'$



3.3.2 Duality: Not Allowing Inefficiency

Allocative efficiency implies that shadow prices equal observed prices. Shephard (1953) showed that the cost function and the distance function are dual to each other. The duality between the cost and distance function can be stated as follows.

$$C(y,w) = \min_x \{wx : D_I(y,x) \geq 1\} \tag{5}$$

$$D_I(y,x) = \min_w \{wx : C(y,w) \geq 1\}, \tag{6}$$

where w is the $(1 \times n)$ vector of input prices. From the above duality between the cost and the distance function, Fare and Primont (1995) show that the solution vector for cost minimization satisfies the following.

$$w = C(y,w)\nabla_x D_I(y,x), \tag{7}$$

where w is the input price vector and $\nabla_x D_i(y,x)$ = $[\partial D_I(y,x)/\partial x_1, \ldots, \partial D_I(y,x)/\partial x_n]$. We interpret x as the cost minimizing solution given (w,y).

3.3.3 Duality: Allowing Allocative Inefficiency

Assuming shadow cost minimization, we can employ a shadow cost function corresponding to the actual cost function in (7) as

$$w^S = C(y,w^S)\nabla_x D_I(y,x), \tag{8}$$

where w^S is the shadow price vector for x. Here, w^S is the price that supports the actual input vector x, where $w^S = [w_1^S, \ldots, w_n^S] = [\phi_1 w_1, \ldots, \phi_n w_n]$. The ϕ_n parameters, $i = 1, \ldots, n$ measure divergence of actual from shadow prices for the firm. The dual relationship of the distance function to the cost function allows us to apply Shephard's lemma to obtain the (cost deflated) shadow prices. The first derivatives of the input distance function with respect to input quantities yield (cost deflated) shadow prices of those inputs (see Blackorby and Russell (1989)). Therefore, the first derivative of input i corresponding to (6) is

$$w_i^S = \frac{\partial D_I(x,y)}{\partial x_i} \cdot C(y, w^S) \tag{9}$$

From equation (7), the relative shadow prices of the input i and j is expressed as [5]

$$\frac{w_i^S}{w_j^S} = \frac{\partial D_I(y,x)/\partial x_i}{\partial D_I(y,x)/\partial x_j} \tag{10}$$

We can calculate allocative efficiency κ_{ij} that is the ratio ϕ_i / ϕ_j as the following.

$$\kappa_{ij} = \frac{\phi_i}{\phi_j} = \frac{w_i^S / w_j^S}{w_i / w_j} = \frac{D_i(\cdot) / D_j(\cdot)}{w_i / w_j}, \tag{11}$$

where $D_i(\cdot) = \partial D_I(y,x)/\partial x_i$. If $\kappa_{ij} = 1$ for all i, j, then the observation is said to be allocatively efficient. If $\kappa_{ij} > 1$, factor i is underutilized relative to j at observed relative prices, and if $\kappa_{ij} < 1$, factor i is overutilized.

[5] This shadow price ratio is closely related to the nonminmal cost literature. See for example Toda(1976) or Atkinson and Halvorsen (1986).

3.4 Stochastic Specification

In this analysis we estimate a generalized translog form of the input distance function.

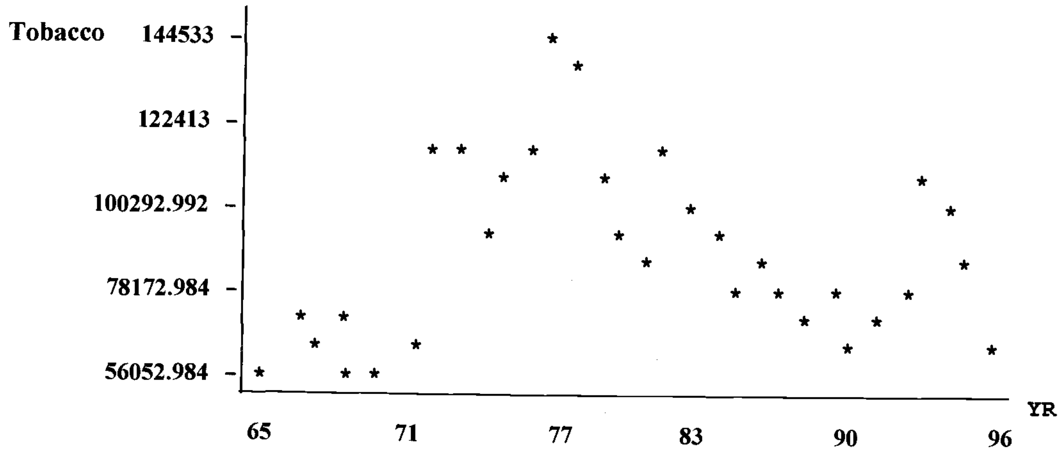
$$\ln[D_I(y,x)\mu_t] = \beta_0 + \sum_k \beta_i \ln y_k + (1/2)\sum_k\sum_i \beta_{ki} \ln y_k \ln y_i + \sum_k\sum_j \alpha_{kj} \ln y_k \ln x_j$$

$$+ (1/2)\sum_i\sum_j \gamma_{ij} \ln x_i \ln x_j + \sum_i \gamma_i \ln x_i + \beta_{t1}t + \beta_{t2}tD \ + \beta_{t3}D \ + \varepsilon_t, \quad (12)$$

where x_i is the input quantity and y_k is the output, $i = 1, \ldots, n$ and $k = 1, \ldots, m$. Note that $\ln\mu_t = \varepsilon_t$. We add a time trend, t to capture technological change over periods. The pattern of the annual data on tobacco leaves, which is the most important raw material in the production of cigarettes, indicates that there might be a structural change in the production technology in 1977.[6] Figure 3.3 shows that the quantity of tobacco leaves decreased dramatically after 1977. To account for this, a dummy variable is included. Define $D = 1$ if before 1977 and zero otherwise. The interaction term of the time-dummy variable is added because the effect of the time trend on technological change in the period before 1977 may differ from the effect of time in the period after 1977.

[6] While the increase rate of the cigarette consumption has fallen due to the anti-smoking movements all over the world in 1970s, that of the Korean cigarette consumption did not fall in 1970s. Except slight decrease between 1982 and 1986, the overall increase rate in the 1980s did not fall, either. In Korea, according to an industry expert, however, the cigarette company's demand for tobacco leaves fell dramatically after 1977 primarily due to an improvement of raw material-saving production technology. See *Report on the Korean monopoly Business*, 4: p 11.

Figure 3.3 Quantity of Tobacco Leaves.



It is possible to determine $D_i(y, x)$ from production data. However, it is not easy to directly determine $C(y, w^s)$ in equation (8) since it is a function of the shadow price vector that we are trying to compute. Let's denote this cost $C(y, w^s)$ as a function of the shadow price vector to be the behavioral cost, C^B, where $C^B = \sum_i \phi_i w_i x_i$. Then equation (9) becomes

$$w_i^S = \frac{\partial D_i(x,y)}{\partial x_i} \cdot C^B = \frac{\partial D_i(x,y)}{\partial x_i} \cdot \sum_i \phi_i w_i x_i \tag{13}$$

Note that C^B is the cost function such that the manager's input choices may be inefficient. Dividing both sides with the actual cost, $C^a = \sum_i w_i x_i$, and recalling that $w_i^S = \phi_i w_i$, the above equation becomes the following.

$$\phi_i w_i / C^a = \frac{\partial D_i(x, y)}{\partial x_i} (\sum_j \phi_j w_j x_j) / C^a \tag{14}$$

Now, if we denote $S_i = w_i/C^a$ as the observed cost-deflated input price of input i, ($i = l, m, k$) and also denote p_2 and p_3 as ϕ_2/ϕ_1 and ϕ_3/ϕ_1, respectively, then we can write cost-deflated input price equations for three different inputs (labor, raw materials and capital) from equation (14) as follows.

$$S_l = \frac{\partial D_I(x, y)}{\partial l} \cdot \frac{(w_l l + p_2 w_m m + p_3 w_k k)}{C^a} \tag{15}$$

$$S_m = \frac{\partial D_I(x, y)}{\partial m} \cdot \frac{(w_l l / p_2 + w_m m + (p_3 / p_2) w_k k)}{C^a} \tag{16}$$

$$S_k = \frac{\partial D_I(x, y)}{\partial k} \cdot \frac{((w_l l) / p_3 + (p_2 / p_3) w_m m + w_k k)}{C^a} \tag{17}$$

Equations (12) and (15) through (17) constitute a system of nonlinear equations. We estimate them in a NLS (Non-linear Least Square) system of equations using the SUR estimation technique. D-W test revealed first-order autocorrelation in the distance function equation. The Hildreth-Lu procedure was used to obtain an efficient estimator.[7] Input and output quantities are treated as exogenous

[7] We replaced the distance function equation in (10) in the system of equations with the following equation.

$y_t - \rho y_{t-1} = (x_t - \rho x_{t-1})\beta + u_t$,

where y_t is $(n \times 1)$ dependent variable vector, x_t is $(n \times k)$ matrix of explanatory variable, β is $(k \times 1)$ vector of coefficient estimates, n is number of observation and k is number of number of explanatory variable. The widely used techniques for finding estimates of ρ was advocated by Hildreth and Lu (1960). See Davidson and Mackinnon (1993) for detail.

variables since the distance function has the advantage for our purpose of being 'agnostic'.[8] The difference between this approach and previous studies is that, in this analysis the shadow price ratios, p_2 and p_3 are included as parameters that are estimated in the system of equations.[9] In fact, in the previous studies, the system of equations are estimated with the restriction $p_2 = p_3 = 1$. However, it might be expected that estimating p_2 and p_3 as a parameter in the system of equations is helpful to obtain more precise coefficient estimates for the distance function in equation (12). Finally, from the derivative of the estimated distance function, κ_{ij} for each observation can be computed by using equation (8).

3.5 Data and Empirical Results

We used annual data for the years 1965-1996 from the Korean cigarette market. Data sources and descriptive statistics are listed in Table 1. The output was categorized into two types, filter and non-filter cigarettes (QF and QNF). The inputs are labor (L), raw materials/tobacco leaves (M), and capital (K). Using labor expenditure, raw materials cost, and the input quantities, input prices for labor and raw materials are calculated. The value of fixed tangible asset (total

[8] The distance function is agnostic with respact to the economic motivation of decision-maker unlike the cost function which is consistent with cost-minimizing behavior.

[9] See Grosskopf and Hayes (1993) or (1997).

productive capital) is used for the capital variable.[10] A proxy for the capital price, we use the market interest rate plus the average depreciation rate in the manufacturing industry. The market interest rate was taken from the bank of Korea and the *Korean statistical yearbook* where it is calculated as the weighted average of the CD, call, and bond yield rate in the manufacturing industry.

Table 1. Descriptive Statistics (Sample Size = 32)

Variable	Units	Mean	Std.Dev.
Outputs:			
QF	10^6 / yr [1, 2, 4]	60165.77753	32185.82019
NQF	10^6 / yr [1, 2, 4]	9160.34747	10075.84892
Inputs:			
L	10^2 / workers [1, 3, 5]	299.50509	39.57924
M	10^6 tons / yr [1, 2, 4]	87930.03125	22881.55143
K	10^6 wons / yr [2, 3]	408131.82642	213530.66020
Input Prices:			
W_L	10^6 wons / yr [1, 5]	461.70705	407.10617
W_M	10^6 wons / yr [1, 2, 4]	3.05720	1.22000
W_K	10^6 wons / yr [1, 5]	0.28007	0.044074
Costs (C):	10^6 wons / yr	506300.9003	242225.68212

Sources:
[1] ***Korean Statistical Yearbook***: various years
[2] Fiscal Loan Division, Treasury Department, Ministry of Finance and Economy
[3] Korean Tobacco and Ginseng Corporation
[4] ***Report on the Korean Monopoly Business***: various years
[5] Bank of Korea

[10] This is based upon the assumption that the monetary value of capital is a monotonic transformation of capital. In distance function analysis this type of capital measure is often used, for example, Coggins and Swinton (1996) and English et al. (1993).

The parameter estimates of the distance function are presented in Table 2. Our estimated input distance function satisfies the general regularity properties. The estimated distance function shows that inputs satisfy monotonicity for all observations and outputs locally satisfy monotonicity. Concavity and convexity are also locally satisfied. In addition, monotonicity, concavity and convexity are all satisfied in the mean sense, i.e., regularity conditions are satisfied when evaluated at mean of x and y, respectively.

Table 2. Coefficient Estimates

Parameter	Estimate	Standard Error	t-statistic
$\beta 0$	-78.1215^{***}	24.0145	-3.25310
$\beta 1$	10.9312^{**}	4.23526	2.58100
$\beta 2$	2.26764^{**}	.863365	2.62652
$\beta 11$	$-.840503^{**}$	.378442	-2.22096
$\beta 12$	$-.193931^{**}$	.072802	-2.66381
$\beta 22$	$-.035261^{**}$	.014079	-2.50443
$\alpha 11$	$.041129^{***}$	.013344	3.08231
$\alpha 21$	$-.028005^{**}$	.012143	-2.30635
$\alpha 31$	$-.013213^{*}$	.718968E-02	-1.83778
$\alpha 12$	$-.010371^{***}$	.189258E-02	-5.47972
$\alpha 22$	.471019E-02**	.171684E-02	2.74352
$\gamma 1$	$.371934^{***}$	.125387	2.96629
$\gamma 2$	$.239034^{*}$	.123209	1.94007
$\gamma 11$	$.082926^{***}$	.021503	3.85641
$\gamma 12$	$-.122969^{***}$	.016746	-7.34331
$\gamma 22$	$.208259^{***}$	.016655	12.5046
$\beta T1$	$-.085127^{**}$	.040606	-2.09640
$\beta T2$	.174441E-02	.013429	.129898
$\beta T3$	1.07854^{*}	.588308	1.83329
ρ	$.41829^{*}$	.134683	1.79554
P2	$.680595^{***}$	.022348	30.4543
P3	$.377805^{***}$	.024845	15.2067

***Significant at the one percent level (two-tailed test).
**Significant at the five percent level (two-tailed test).
*Significant at the ten percent level (two-tailed test).

3.5.1 Allocative Efficiency

For each input, we calculate allocative efficiency κ_{ij} using equation (9). The point estimates of observation specific κ_{ij} are provided in Table 3. For 32 observations, the Korean firm overutilized raw materials (tobacco leaves) compared to labor. The firm also overutilized capital compared to raw materials.

Table 3. Allocative Efficiency

Year	K21	K31	K32
1965	0.64420	0.40092	0.62235
1966	0.67329	0.37755	0.56075
1967	0.74043	0.37376	0.50478
1968	0.84364	0.44273	0.52479
1969	0.76615	0.32522	0.42449
1970	0.70263	0.36993	0.52650
1971	0.55689	0.40804	0.73271
1972	0.53260	0.47610	0.89392
1973	0.53831	0.38665	0.71827
1974	0.50074	0.25978	0.51880
1975	0.49262	0.27239	0.55294
1976	0.54912	0.37512	0.68312
1977	0.61247	0.35833	0.58505
1978	0.66774	0.35776	0.53578
1979	0.67139	0.37611	0.56020
1980	0.62560	0.26124	0.41759
1981	0.62985	0.31028	0.49262
1982	0.66982	0.32489	0.48504
1983	0.72133	0.36722	0.50908
1984	0.76724	0.45538	0.59353
1985	0.68237	0.38267	0.56079
1986	0.70613	0.38787	0.54929
1987	0.64630	0.36757	0.56873
1988	0.61989	0.30464	0.49145
1989	0.60915	0.27925	0.45842
1990	0.64232	0.37820	0.58881
1991	0.57096	0.34166	0.59839
1992	0.58030	0.34795	0.59961
1993	0.59647	0.34024	0.57042
1994	0.68632	0.37136	0.54109
1995	0.80544	0.41439	0.51449
1996	0.97071	0.56665	0.58375

This seems to be consistent with one of the characteristics of Korean cigarette industry. The Korean governmental firm has been encouraged to purchase more than the optimal quantity of tobacco leaves by paying a favorable price in order to protect local tobacco farmers.[11] Although there is no clear explanation for capital overutilization, one possible hypothesis is that capital overutilization occurs since the Korean governmental firm has access to loans at sub-market interest rates.

3.5.2 Technical Efficiency

To obtain measures of technical efficiency, the technique of decomposing error term is used. If we allow for random error as well as technical inefficiency, we can assume the error of the distance function equation is a composed error:

$$\varepsilon_t = -u_t + v_t,\ u_t \geq 0 \tag{16}$$

The first term u_t is half normally distributed with variance, σ_u^2 and captures technical inefficiency. The second term v_t allows for random shocks and it is white noise with zero mean and variance, σ_v^2. However, our estimates are based on the assumption of a white noise error term. Therefore the residuals from our estimation obviously have some upward bias. The residuals from the estimation $\hat{\varepsilon}_t$ can be expressed as

[11] The Korean cigarette company makes a yearly contract with farmers such that the company agrees to purchase all tobacco leaves that farmers produce.

$$\hat{\varepsilon}_t = a + \varepsilon_t, \tag{17}$$

where a is a positive constant. If we treat $\hat{\varepsilon}_t$ as a dependent variable and the constant term as an independent variable, estimates of the bias a, σ_u^2, and σ_v^2 can be obtained from the stochastic frontier estimation.

Next, based on the conditional distribution of u_t given ε_t, the point estimates of u_t are calculated using the following formula. Expected u_t is

$$E(u \mid \varepsilon) = \sigma^* [\frac{\phi(\varepsilon\lambda / \sigma)}{1 - \Phi(\varepsilon\lambda / \sigma)} - \frac{\varepsilon\lambda}{\sigma}],$$

where $\sigma^* = \frac{\sigma_u \sigma_v}{\sigma}$; $\sigma = (\sigma_u^2 + \sigma_v^2)^{1/2}$ and $\lambda = \frac{\sigma_u}{\sigma_v}$; ϕ is the standard normal density, Φ is the cumulative density, and observational subscripts have been dropped. We specify the estimable distance function as $D_i(x,y)\cdot\mu_t$ so that $\ln[D_i(x,y)\cdot\mu_t] = \ln D_i(x,y) + \ln\mu_t$. Since $ln\mu_t = \varepsilon_t$ in our distance function equation in (10), we can rewrite the distance function as $1 = D_i(x,y)\cdot\exp\{-u_t + v_t\}$. Recall that the input distance function is the reciprocal of the Farrell input-oriented measure of technical efficiency. The technical efficiency measure for each observation is

$$EFF = \frac{1}{D(y, x; \hat{\beta})\exp\{\hat{v}\}} = \frac{1}{\exp\{E(u \mid \varepsilon)\}} \text{, where } \hat{v} = \varepsilon + E(u \mid \varepsilon).$$

Measures of technical efficiency for each observation are provided in Table 4.

Table 4. Technical Efficiency

Year	*EFF*
1966	0.97646
1967	0.97690
1968	0.97613
1969	0.97823
1970	0.97747
1971	0.97634
1972	0.96876
1973	0.97330
1974	0.97638
1975	0.97587
1976	0.97587
1977	0.97431
1978	0.97547
1979	0.97713
1980	0.97765
1981	0.97826
1982	0.97444
1983	0.97653
1984	0.97615
1985	0.97697
1986	0.97576
1987	0.97606
1988	0.97586
1989	0.97605
1990	0.97759
1991	0.97676
1992	0.97673
1993	0.97289
1994	0.97702
1995	0.97649
1996	0.97752

3.5.3 Hypothesis Test and Bootstrapping

To see the impact of competition on allocative efficiency we compare the average of κ_{ij} in years from 1977 to 1987 to the average of κ_{ij} in years from 1988 to 1996. Since there was a structural change of production technology in 1977, the period from 1965 to 1976 is excluded. The major reason for the different efficiency level during this period seems to be the different technology rather than the market opening in 1988. Table 5 provides the average efficiency of both allocative and technical efficiency calculated from our estimation results for both sub-periods.

Table 5. Average Efficiency Scores before and after 1988

1. Average Allocative Efficiency

	$\kappa 21$	$\kappa 31$	$\kappa 32$
1977-1987	0.67575	0.35903	0.53252
1988-1996	0.68563	0.37511	0.54700

2. Average Technical Efficiency

	EFF
1977-1987	0.97625
1988-1996	0.97632

Both efficiencies after 1988 are greater than before. However, in order to undertake a hypothesis test of whether the level of allocative efficiency after 1988 is statistically different (increased) from allocative efficiency before 1988, we need the distribution of the average of κ_{ij}. Since κ_{ij} is a function of the estimated coefficients in equation (9), it also has distributions. Rather than assume a distribution, a bootstrap based on the residuals of the system of equations is performed to construct an empirical distribution. New dependent variables were created by adding predicted values of the dependent variables to newly selected residuals using random draw with replacement. With the new dependent variables, the system of equations was estimated 1000 times.[12] Then κ_{ij} was calculated for each observation based on the coefficient estimates obtained from the replicated estimation. Then, the average of κ_{ij} that was calculated in such a way, therefore, can provide a distribution with the replicated number of elements.

Finally, using Fisher's permutation test,[13] the hypothesis test was conducted. The null hypothesis is that the average κ_{ij} in the first period (before 1988) is not different from κ_{ij} in the second period (after 1988). For all κ_{21}, κ_{31} and κ_{32}, the average efficiency level after 1988 is higher than before 1988 and the null hypothesis was rejected at the 1% significance level.

[12] Results from Hall (1986) suggest 1000 times is appropriate for estimation of confidence intervals.

[13] The bootstrap test statistic for testing equality of means in two different samples was suggested by Fisher in 1930s. See Efron and Tibshirani (1993 chapter 15).

Similarly, the same bootstrapping technique is used to construct a distribution for technical efficiency and Fisher test is applied. The average technical efficiency level after 1988 increased and at the 1% significance level the null hypothesis that there is no change in technical efficiency after1988 is rejected.

3.6 Conclusion

Since the import of cigarettes from foreign countries was allowed in 1988, the monopoly Korean cigarette market became an oligopoly among the Korean firm and foreign firms. In this paper we empirically examine whether enhanced competition in the Korean cigarette market due to the 1988 structural change of the market has increased been associated with efficiency of the Korean firm. An input distance function and its corresponding duality to the cost function are employed to set up the estimating equations. The duality between the cost and distance function allows us to measure input shadow prices and calculate allocative efficiency. Since no optimization is presumed, i.e., not actual costs but shadow or behavioral costs are minimized, the duality equations for each input explicitly include the shadow prices as parameters to be estimated. In order to conduct hypothesis tests a bootstrapping technique was used.

The average efficiency levels in the period before 1988 were compared to those in the period after 1988. According to Fisher's permutation test, at the 1% significance level, we find overutilization of raw materials compared to labor, and capital compared to raw materials, decreased after 1988. Also, with 1% significance level, evidence was found that the technical efficiency improved after 1988.

In summary we find empirical support for the central hypothesis of this paper that competition promotes efficiency in the Korean cigarette market. Our findings with respect to allocative efficiency also are revealing the behavior of the Korean firm: the over-use of raw materials (tobacc0 leaves) reflects favorable treatment of Korea's tobacco growers; the over-use of capital suggests access to loans at sub-market rates; and finally that the firm does not overuse labor indicates that the firm is not an employer of resort, a common characteristic of state ownership world wide. Even though both efficiencies increased after 1988 market opening, the differences of average efficiencies over two periods seem to be minimal. We do not know actually how much costs are saved by this slight efficiency gain due to the enhanced competition after market opening. This issue remains an interesting and important topic for future research.

4. CONCLUSIONS AND DISCUSSION

The main objective of this thesis is to analyze the behavior of economic agents and corresponding market outcomes in the presence of market imperfections. Chapter 2 analyzes the strategic interaction between market participants under *asymmetric information.* Chapter 3 empirically investigates the relationship between *competition* and *efficiency*.

In chapter 2 we present a dynamic signaling model between a monopolist manufacturer and a monopolist retailer, where only the retailer is privately informed about his/her local demand. Unlike previous signaling games, the signal receiver (manufacturer) is the first mover in this model. From this study we find that (i) the retailer's inventory stock strategically affects the bargaining power to lower the next period wholesale price. This outcome occurs even under no demand uncertainty, (ii) *strategic interaction* and *asymmetric information* explain the observation that retail price may not adjust to new demand conditions by showing that both pooling and separating equilibriums exist, (iii) the pooling equilibrium survives Cho-Kreps intuitive criterion, (iv) our model with the new game structure generates a smaller set of equiliria than a typical signaling game produces.

In chapter 3 we investigate whether or not the increased level of competition from trade exposure increases the efficiency of the single cigarette producer in Korea. An input distance function and corresponding duality to cost function were employed to specify an estimable system of equations. A behavioral cost function is included in the input price equations. Bootstrapping is used to test hypothesis about competition and firm efficiency. Results in chapter 3 show that (i) both allocative and technical efficiency have increased with the introduction of foreign competition in 1988, (ii) for the entire observation period, raw materials have been overutilized compared to labor and capital has been overutilized compared to raw materialss, (iii) the utility maximizing governmental company valued tobacco farmers protection more than labor overutilizaton.

Conclusively, we show that, through an applied theory model and an empirical analysis, the market outcome may depart from *perfect competition outcome* when there exist frictional factors of *market imperfections*. The importance of this research in chapter 2 is that we show asymmetric information and strategic interactions between retailers and wholesalers explain the observed staggering-retail price adjustment behavior without traditional explanations such as menu costs. In addition, we find interesting results associated with retailer's inventory stock and set of equilibria that inventory model and signaling game literature have not addressed yet in their literatures. In chapter 3 we provide an empirical study with the Korean cigarette market data. This study confirms economic theory by supporting the hypothesis that *competition* promotes market and *firm efficiency*. Also, this study analyzes the bureaucrat input choice behavior which is still an open question.

Our research in this thesis is limited in various ways. Further study on the procedure of forming prior beliefs and the infinite horizon model would generate rich implications on topics associated with the signaling game. In addition, measuring the profit gain (or the cost saving) from greater efficiency due to enhanced competition remains an interesting and important topic for future research.

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APPENDICES

Appendix A: The retailer's Profit as a function of r_1

A.1 If $r_1 < 3\theta^S\delta/4$

We know $p_1 = \frac{1}{2}\theta + \frac{1}{2}r_1$, $q_1 = \theta - \frac{1}{2}r_1 - \frac{2r_1}{3\delta}$, $x = \frac{1}{2}\theta - \frac{2r_1}{3\delta}$, $r_2 = \frac{3}{2}\theta - (p_1 + q_1)$, and $p_2 = \frac{1}{2}\theta + \frac{1}{2}r_2$.

We ignore the superscript representing each state, $S = L, H$ for the moment. Using these solutions, we can obtain followings.

$(1)\, r_2 = \frac{2r_1}{3\delta}$ $\quad (2)\, q_2 = \frac{r_1}{3\delta}$ $\quad (3)\; p_2 = \frac{1}{2}\theta + \frac{r_1}{3\delta}$

The profit of the retailer is

(4) $\Pi^B = p_1(\theta - p_1) - r_1 q_1 + \delta[\, p_2(\theta - p_2) - r_2 q_2\,]$

If we substitute p_1, q_1, r_2, p_2, and q_2 into the profit function in equation (4), we can obtain

(5) $\Pi^B = (\frac{1}{4} + \frac{1}{3\delta})r_1^2 - \theta^S r_1 + \frac{1}{4}\theta^S(\theta^S + \delta)$, $S = H, L$

In our example ($\theta^H = 1$, $\delta = 1$) the high type retailer's profit is

(6) $\Pi^{BH} = 7r_1^2/12 - r_1 + 1/2$

A.2 If $r_1 \geq 3\theta^S\delta/4$

Since $x = 0$, in the case where $r_1 \geq 3\theta\delta/4$, correspondingly, $r_2 = \frac{1}{2}\theta$, and $p_2 = \frac{1}{2}\theta + \frac{1}{2}r_2 = \frac{3}{4}\theta$.

Also, since there is no inventory, the sales equals order quantity in each period, $q_1 = \theta - p_1$ and $q_2 = \theta - p_2$. Then profit of the retailer in equation (4) can be rewritten as

(7) $\Pi^B = (p_1 - r_1)(\theta - p_1) + \delta[(p_2 - r_2)(\theta - p_2)]$

If we substitute p_1, q_1, r_2, p_2, and q_2 into the profit function in equation (7), we can obtain

(8) $\Pi^B = \frac{1}{4}r_1^2 - \frac{1}{2}\theta^S r_1 + (\frac{1}{4} + \frac{\delta}{16})\theta^{S2}$, $S = H, L$

In our example the high type retailer's profit is

(9) $\Pi^{BH} = r_1^2/4 - r_1/2 + 5/16$

Appendix B: Pooling Equilibrium

B.1 Second Period Wholesale Price to Pooling Strategy

We know that $r_2^P = 0.23$, $q_2^H(r_2^P) = 0.385$, $q_2^L(r_2^P) = 0.085$

$E\Pi_2^A(r_2^P) = r_2^P[\lambda(q_2^H(r_2^P)) + (1 - \lambda)(q_2^L(r_2^P))] = 0.23[0.1(0.385) + 0.9(0.085)]$

$= 0.02645$

Since $q_1^P + p_1^P = 0.55 < \theta^H = 1$, the high type's inventory $x^H = 0$. Corresponding $r_2^H = \theta^H/2 = 1/2$ and $q_2^H(r_2^H) = \theta^H - p_2^H = \theta^H/4$.

In this case optimal $q_2^L(r_2^H) = 0$ since any positive $q_2^L(r_2^H)$ yields only negative profit in period 2 given $r_2^H = 1/2 = \theta^L$.

$E\Pi_2^A(r_2^H) = r_2^H[\lambda(q_2^H(r_2^H))] = 0.5(0.1)(0.25) = 0.0125$

The condition **1.** ***iii*** is satisfied since $E\Pi_2^A(r_2^P) = 0.085 > E\Pi_2^A(r_2^H) = 0.0125$

B.2 The Retailer's Profits

B.2.a The High Type's Profit: Pooling

$$\Pi^{BH}(P) = (p_1^P - r_1)q_1^P + \delta[p_2^H(r_2^P)(\theta^H - p_2^H(r_2^P)) - r_2^P q_2^H(r_2^P)],$$

where P in parenthesis denotes pooling strategy. The optimal choices of the retailer in the second period as functions of r_2^P are

$p_2^H(r_2^P) = 0.615$

$\theta^H - p_2^H(r_2^P) = 1 - 0.615 = 0.385$

$q_2^H(r_2^P) = 0.385$ (since $x^H = 0$ and $\theta^H - p_2^H(r_2^P) = q_2^H(r_2^P)$)

(1) $\Pi^{BH}(P) = (0.445 - r_1)0.105 + [(0.385)^2]$

$= (0.445 - r_1)0.105 + [0.148225] = 0.19495 - 0.105r_1$

Note that $\delta = 1$ in our example.

B.2.b The High Type's Profit: Deviating

If the retailer deviates from pooling strategy, the manufacturer will believe it is the high type and correspondingly, he will charge r_2^H to the retailer. Thus, the maximum profit of the retailer when deviating is going to be the same as the profit under complete information.

(i) $r_1 \leq 3\theta^H/4 = 0.75$

(2) $Max\{\Pi^{BH}(D)\} = 7r_1^2/12 - r_1 + 1/2$, where D denotes deviating.

(ii) $r_1 > 3\theta^H/4 = 0.75$

Similarly, the maximum profit when deviating is identical to the profit under complete information.

(3) $Max\{\Pi^{BH}(D)\} = \Pi^{BH} = r_1^2/4 - r_1/2 + 5/16$ (see appendix A)

B.2.c The Low Type's Profit: Pooling

The profit of the retailer when pooling is

$$\Pi^{BL}(P) = p_1^P(\theta^L - p_1^P) - r_1 q_1^P + \delta[p_2^L(r_2^P)(\theta^L - p_2^L(r_2^P)) - r_2^P q_2^L(r_2^P)]$$

Since $p_1^P + q_1^P > \theta^L$, the first period profit is $p_1^P(\theta^L - p_1^P) - r_1 q_1^P$. Optimal solutions as functions of r_2^P are

$$p_2^L(r_2^P) = (\theta^L + r_2^P)/2 = (0.5 + 0.23)/2 = 0.365$$

$$\theta^L - p_2^L(r_2^P) = 0.5 - 0.365 = 0.135$$

$$q_2^L(r_2^P) = \theta^L - p_2^L(r_2^P) - x^L = 0.085$$

Therefore,

$$(4)\ \Pi^{BL}(P) = (0.445)(1/2 - 0.445) - 0.105r_1 + [0.365(0.135) - 0.23(0.085)]$$

$$= (0.024475) - 0.105r_1 + [0.029725] = 0.0542 - 0.105r_1$$

B.2.d The Low Type's Profit: Deviating

(i) $r_1 \le \theta^L = 0.5$

If the retailer deviates from pooling strategy, the manufacturer will believe it is the high type and correspondingly, he will charge r_2^H to the retailer. Even if the low type retailer has a positive amount of inventory, the manufacturer believes it is the high type and so, he believes the retailer's inventory is 0 since $p_1^L + q_1^L$ is always less than θ^H. Therefore, the manufacturer charges $r_2^H = \theta^H/2 = \theta^L$. Hence any order quantity in second period with paying this wholesale price cannot yield positive profit. So, the low type retailer's second period order quantity will be zero and therefore, the only second period sales and retail price are x^L and $(\theta^L - x^L)$, respectively. Thus, the maximum profit of the retailer when deviating is going to be the following.

$$Max\{\Pi^{BL}(D)\} = p_1^L(\theta^L - p_1^L) - r_1(\theta^L - p_1^L + x^L) + \delta[x^L(\theta^L - x^L)]$$

First order conditions are:

F.O.C) (5) p_1^L: $\theta^L - 2p_1^L - r_1 = 0$

(6) x^L : $-r_1 + \theta^L - 2x^L = 0$

Using equation (5) and (6),

$p_1^L = (\theta^L + r_1)/2$ and $q_1^L = (\theta^L - r_1)/2$ since $q_1^L = \theta^L - p_1^L$.

$x^L = (\theta^L - r_1)/2$

Thus,

$$(7)\ Max\{\Pi^{BL}(D)\} = ((\theta^L + r_1)/2)((\theta^L - r_1)/2) - r_1((\theta^L - r_1)/2 + (\theta^L - r_1)/2)$$

$$+ [((\theta^L - r_1)/2)((\theta^L + r_1)/2)]$$

$$= 1/4(\,1/4 - r_1^2) - r_1(1/2 - r_1) + 1/4(\,1/4 - r_1^2)$$

$$= 1/2(\,1/4 - r_1^2) - r_1(1/2 - r_1)$$

(ii) $r_1 > \theta^L = 0.5$

if $r_1 > \theta^L = 0.5$, then $x^L = 0$ and $q_1^L = 0$, since $x^L = (\theta^L - r_1)/2$ and $q_1^L = (\theta^L - r_1)/2$. Therefore, $\theta^L - p_1^L$ is also zero and the profit is

$$(8)\ Max\{\Pi^{BL}(D)\} = p_1^L(\theta^L - p_1^L) - r_1(\theta^L - p_1^L + x^L) + \delta[x^L(\theta^L - x^L)] = 0$$

B.3 Range of r_1 for Existence of Pooling Equilibrium

B.3.a The Range for High Type

(i) $r_1 \leq 3\theta^H/4 = 0.75$

To satisfy the condition for existence of pooling equilibrium, the profit in equation (1) must be greater or equal to the maximum profit when deviating in equation (2). Therefore, the following must be satisfied.

$0.19495 - 0.105r_1 \geq 7r_1^2/12 - r_1 + 1/2$

$7r_1^2/12 - 0.895r_1 + 0.30505 \leq 0$

$r_1^2 - 1.53428r_1 + 0.52294 \leq 0$

$0.51109 \leq r_1 \leq 1.023197$

In this case, since r_1 must be greater than 0.75, the range r_1 for is the following.

Result 1: $0.51109 \leq r_1 \leq 0.75$

(ii) $r_1 > 3\theta^H/4 = 0.75$

For existence of pooling equilibrium, also the profit in equation (1) must be no less than the profit in equation (3) as the following.

$0.19495 - 0.105r_1 \geq 0.3125 - 0.5r_1 + 0.25r_1^2$, multiply both terms by 4,

$0.7798 - 0.42r_1 \geq r_1^2 - 2r_1 + 1.25$

$r_1^2 - 1.58r_1 + 0.4702 \leq 0$

$0.3977 \leq r_1 \leq 1.1823$

In this case, since r_1 must be less or equal to 0.75 the range for r_1 is the following.

Result 2: $0.75 < r_1 \leq 1.1823$

B.3.b The Range for Low Type

(i) $r_1 \leq \theta^L = 0.5$

To satisfy the condition for existence of pooling equilibrium, the profit in equation (4) must be greater or equal to the maximum profit when deviating in equation (7). Therefore, the following must be satisfied.

$0.0542 - 0.105r_1 \geq r_1^2/2 - r_1/2 + 1/8$

$r_1^2/2 - 0.395r_1 + 0.0708 \leq 0$, multiply both terms by 2,

$r_1^2 - 0.79r_1 + 0.1416 \leq 0$

$0.2749 \leq r_1 \leq 0.5151$

In this case, since r_1 must be less than 0.5, the range r_1 for is the following.

Result 3: $0.2749 \leq r_1 \leq 0.5$

(ii) $r_1 > \theta^L = 0.5$

To satisfy the condition for existence of pooling equilibrium, the profit in equation (4) must be greater or equal to the maximum profit when deviating in equation (8). Therefore, the following must be satisfied.

$0.0542 - 0.105r_1 \geq 0$

Result 4: $r_1 \leq 0.5162$

Combining **Result 1 - 4:** pooling equilibrium exists when the manufacturer charges the first period wholesale price to the retailer in the following range,

Result 5: $0.51109 \leq r_1 \leq 0.5162$

B.4 Expected Profit of the Manufacturer in Pooling Equilibrium

$$\Pi^A(p) = r_1 q_1^P + r_2^P[\lambda(q_2^H(r_2^P)) + (1 - \lambda)(q_2^L(r_2^P))]$$

$$\Pi^A(p) = 0.5162(0.105) + 0.23[0.1(0.385) + 0.9(0.085)] = 0.05420 + 0.02645$$

$$= \mathbf{0.08065}$$

Appendix C: Separating Equilibrium

C.1 If $r_1 > 3\delta\theta^H/4$

Since r_1 is greater than $3\delta\theta^H/4$, optimal q_1^H is $(\theta^H + r_1)/2$. The high type retailer's profit from revealing his type is then

$$\Pi^{BH}(R) = p_1(\theta^H - p_1) - r_1 q_1 + \delta[(\frac{\theta^H}{2} - \frac{r_2^H}{2})^2]$$

$$= (\frac{1}{2} - \frac{r_1}{2})^2 + \frac{1}{16} = \frac{1}{4}(1 - 2r_1 + r_1^2) + \frac{1}{16}$$

$$= 0.3125 - 0.5r_1 + 0.25r_1^2$$

Profit from mimicking the low type is

$$\Pi^{BH}(M)=(p_1-r_1)q_1^{\ L}-r_1q_1^{\ L}+\delta[p_2^H(r_2^L)(\theta^H-p_2^H(r_2^L))-r_2^Lq_2^L(r_2^L)]$$

Note that R and M denotes revealing and mimicking, respectively. Since $r_1 > \theta^L$, optimal $q_1^{\ L}$ is 0. If the high type mimics the low type by choosing $q_1^{\ L} = 0$, the high type can face the whole sale price in the second period $r_2^{\ L} = \theta^L/2 = ¼$. Then $p_2^{\ H}$ as a function of $r_2^{\ L}$ is

$$p_2^{\ H}(r_2^{\ L}) = (\theta^H + r_2^{\ L})/2.$$

$$\Pi^{BH}(M) = [\frac{(\theta^H + r_2^L)}{2}\frac{(\theta^H - r_2^L)}{2} - r_2^L\frac{(\theta^H - r_2^L)}{2}] \text{ Note that } q_2^{\ H} = \theta^H - p_2^{\ H}.$$
$$= [(\theta^H - r_2^L)^2/4] = [(1-0.25)^2/4] = 0.140625$$

If the profit from revealing is greater than the profit from mimicking, then separating equilibrium is identical to the solution under complete information (no envy case):
if $0.3125 - 0.5r_1 + 0.25r_1^{\ 2} < 0.140625$

$0.441 < r_1 < 1.559$

Therefore, for $r_1 > 0.75$, separating equilibrium is that each type chooses the complete information solution fully revealing his type.

C.2 If $\theta^L \le r_1 \le 3\theta^H/4 = 0.75$

C.2.a Envy Case

The retailer's profits when revealing and mimicking are, respectively,

$$\Pi^{BH}(R) = 7r_1^{\ 2}/12 - r_1 + 1/2$$

$$\Pi^{BH}(M) = (p_1 - r_1)q_1^{\ L} + \delta[p_2^{\ H}(r_2^{\ L})(\theta^H - p_2^{\ H}(r_2^{\ L})) - r_2^{\ L}q_2^{\ H}(r_2^{\ L})]$$

$$= 0 + [0.140625],$$

where R and M in parentheses denote revealing and mimicking, respectively. Since $r_1 \ge \theta^L$, optimal $q_1^{\ L} = 0$ and the manufacturer will charge $r_2^{\ L}$ base on belief that $q_1^{\ L} = 0$ and $x^L = 0$, so, $r_2^{\ L} = \theta^L/2 = 1/4$. Then $q_2^{\ H}(r_2^{\ L}) = 3/8$ and $\Pi_2^{BH}(M) = [q_2^{\ H}(r_2^{\ L})]^2$. Note that $p_2^{\ H}(r_2^{\ L}) - r_2^{\ L} = q_2^{\ H}(r_2^{\ L})$ in this case where $x = 0$.

For $\Pi^{BH}(R) \leq \Pi^{BH}(M)$

$7r_1^2/12 - r_1 + ½ \leq 0.140625$

$r_1^2 - 12r_1/7 + 0.61607 \leq 0$

$0.5127 \leq r_1 \leq 1.1795$

Therefore, for $0.5127 \leq r_1 \leq 0.75$ it is envy case (there is an incentive for mimicking). To prevent mimicking the L type must choose q_1^L and p_1^L such that

$$(*)\ \Pi^{BH}(p_1^L, q_1^L | \theta^H, r_2^L) \leq \Pi^{BH}(p_1^H, q_1^H | \theta^H, r_2^H)$$

If $q_1^L > 0$, then $x^L = q_1^L$ (since $r_1 > \theta^L$) and $r_2^L = \theta^L/2 - x^L = ¼ - q_1^L$.

$$p_2^H(r_2^L) = (\theta^H + r_2^L)/2 = 0.5 + (1/4 - q_1^L)/2 = 5/8 - q_1^L/2$$

$$p_2^H(r_2^L) - r_2^L = (\theta^H - r_2^L)/2 = 3/8 + q_1^L/2$$

$$q_2^H(r_2^L) = \theta^H - p_2^H(r_2^L) - x^L = 1 - (5/8 - q_1^L/2) - q_1^L = 3/8 - q_1^L/2$$

$$\Pi^{BH}(p_1^L, q_1^L | \theta^H, r_2^L) = - r_1 q_1^L + \delta[(5/8 - q_1^L/2)(3/8 + q_1^L/2)$$
$$- (1/4 - q_1^L)(3/8 - q_1^L/2)]$$
$$= - r_1 q_1^L + [0.140625 + 0.625q_1^L - 3(q_1^L)^2/4]$$

$$\Pi^{BH}(p_1^H, q_1^H | \theta^H, r_2^H) = 7r_1^2/12 - r_1 + 1/2$$

To satisfy (*) the following must be true.

$$4[\Pi^{BH}(p_1^L, q_1^L | \theta^H, r_2^L) - \Pi^{BH}(p_1^H, q_1^H | \theta^H, r_2^H)]$$
$$= - 3(q_1^L)^2 + (2.5 - 4r_1)\, q_1^L + 0.5625 - (7r_1^2/3 - 4r_1 + 2) \leq 0$$

However, this is always positive given the range of r_1. Thus, there is no way to make the high type not to mimic the low type even though the high type retailer has an incentive to mimic the low type. Therefore, there is no separating equilibrium in this case.

C.2.b No Envy Case

If $0.5 \leq r_1 < 0.5127$, then in separating equilibrium the each type reveals it's type by choosing the solution under complete information.

C.3 If $3\theta^L/4 \leq r_1 < \theta^L$

$\Pi^{BH}(R) = 7r_1^2/12 - r_1 + 1/2$

For this range of r_1, the low type retailer chooses $q_1^L = (\theta^L - r_1)/2$ and $x^L = 0$ and correspondingly, $r_2^L = \theta^L/2$. Therefore,

$$\Pi^{BH}(M) = (p_1 - r_1)q_1^L + \delta[p_2^H(r_2^L)(\theta^H - p_2^H(r_2^L)) - r_2^L q_2^H(r_2^L)]$$

$$= (\theta^{L2} - r_1^2)/4 + \delta[(\theta^L/2 - r_2^L/2)^2] = (1/4 - r_1^2)/4 + 0.140625$$

For $\Pi^{BH}(R) \leq \Pi^{BH}(M)$ the following must be satisfied.

$7r_1^2/12 - r_1 + ½ \leq (1/4 - r_1^2)/4 + 0.140625$

This can be rewritten as $r_1^2 - 1.2r_1 + 0.35625 \leq 0$

$0.539 \leq r_1 \leq 0.661$

The range of r_1 satisfying the condition for envy case exceeds $\theta^L = 0.5$. Therefore, within the range, $3\theta^L/4 \leq r_1 < \theta^L$, it is always no envy case.

C.4 If $r_1 < 3\theta^L/4$

For this range of r_1 optimal solutions for the low type are followings.

$q_1^L = \theta^L - r_1/2 - 2r_1/3\delta = \theta^L - 7r_1/6$ (since $\delta = 1$ in this example)

$p_1^L = (\theta^L + r_1)/2$

$q_1^L + p_1^L = 3\theta^L/2 - 2r_1/3\delta$

In this case $r_2^L = 3\theta^L/2 - (q_1^L + p_1^L) = 2\, r_1/3\delta$

$\Pi^{BH}(R) = 7r_1^2/12 - r_1 + 1/2$

$\Pi^{BH}(M) = (p_1 - r_1)q_1^L + \delta[p_2^H(r_2^L)(\theta^H - p_2^H(r_2^L)) - r_2^L q_2^H(r_2^L)]$

The low type retailer has positive inventory stock in this case. However, the maximum $q_1^L + p_1^L = 3\theta^L/2 = ¾$ (when $r_1 = 0$). This is less than $\theta^H = 1$, so, the high type will not have any inventory when he mimics the low type. Therefore, $\theta^H - p_2^H(r_2^L) = q_2^H(r_2^L)$ and the second period profit for the high type is

$\Pi_2^{BH}(M) = [(\theta^H - p_2^H(r_2^L))]^2 = (\theta^H/2 - r_2^L/2)^2 = ¼ - r_1/3 + r_1^2/9$

Then the total profit for the high type is

$\Pi^{BH}(M) = (\theta^L/2 - r_1/2)(\theta^L - 7r_1/6) + ¼ - r_1/3 + r_1^2/9 = 3/8 - 7r_1/8 + 25r_1^2/36$

For $\Pi^{BH}(R) \leq \Pi^{BH}(M)$ the following must be satisfied.

$7r_1^2/12 - r_1 + 1/2 \leq 3/8 - 7r_1/8 + 25r_1^2/36$

This can be rewritten as

$A = r_1^2/9 + r_1/8 - 1/8 \geq 0$

Since $\partial A/\partial r_1 = 2r_1/9 + 1/8 > 0$, minimum of A is obtained when $r_1 = 3\theta^L/4 = 0.375$.

$A|_{r1=0.375} = (0.375)^2/9 + (0.375)/8 - 1/8 = -0.0625 < 0$.

Thus, the condition that mimicking profit is greater than revealing never be satisfied. Therefore, for this range of r_1, it is no envy case and separating equilibrium is identical to the solution under complete information.

Appendix D: Profits of the Manufacturer in Separating Equilibrium

The manufacturer's profit in separating equilibrium is

$$\Pi^A(S) = r_1[\lambda(q_1^H) + (1 - \lambda)(q_1^L)] + [\lambda(r_2^H q_2^H) + (1 - \lambda)(r_2^L q_2^L)]$$

D.1 If $r_1 < 3\theta^L/4$

Under this range of r_1, the equilibrium is no envy case where the retailer reveals his type by choosing complete information solution.

$q_1^L = \theta^L - 7r_1/6 = 1/2 - 7r_1/6$ (since $\delta = 1$ in our example)

$q_1^H = \theta^H - 7r_1/6 = 1 - 7r_1/6$

Note that $r_2^S = 3\theta^S/2 - (q_1^S + p_1^S) = 3\theta^S/2 - (3\theta^S/2 - 2r_1/3\delta) = 2r_1/3\delta = 2r_1/3$

Note that $q_2^S = 2\theta^S - p_2^S - (q_1^S + p_1^S) = 2\theta^S - (\theta^S + r_2^S)/2 - (q_1^S + p_1^S)$

$$= (3\theta^S/2 - (q_1^S + p_1^S))/2 = r_1^S/2 = r_1/3\delta = r_1/3$$

The manufacturer's profit is

$$\Pi^A(S) = r_1[\lambda(q_1^H) + (1 - \lambda)(q_1^L)] + [\lambda(r_2^H q_2^H) + (1 - \lambda)(r_2^L q_2^L)]$$

$$= r_1[0.1(1 - 7r_1/6) + 0.9(1/2 - 7r_1/6)] + [0.1(2r_1^2/9) + 0.9(2r_1^2/9)]$$

$$= r_1[0.1 + (0.9)/2 - 7r_1/6)] + [2r_1^2/9]$$

$$= 0.55r_1 - 7r_1^2/6 + 2r_1^2/9 = 0.55r_1 - 17r_1^2/18$$

$\partial\Pi^A(S)/\partial r_1 = 0.55 - 34r_1/18 = 0$; $r_1 = 0.55(9/17) = 0.29118$

$\Pi^A(S)$ is maximized when $r_1 = 0.29118$ since $\partial^2\Pi^A(S)/\partial r_1^2 = -17/9 < 0$.

$\Pi^A(S)|_{r1=0.29118} = 0.55(0.29118) - 17(0.29118)^2/18 =$ **0.08007**

D.2 If $3\theta^L/4 \le r_1 < \theta^L$

Equilibrium is also no envy case. The each type retailers' solutions are

$q_1^L = \theta^L/2 - r_1/2 = 1/4 - r_1/2$ and $q_2^L = \theta^L/4 = 1/8$ (since $x^L = 0$ and $r_2^L = \theta^L/2 = 1/4$)

$q_1^H = \theta^H - 7r_1/6 = 1 - 7r_1/6$ (since $\delta = 1$ in our example)

$r_2^H = 2r_1/3$ and $q_2^H = r_1/3$

Then the manufacturer's profit is

$$\Pi^A(S) = r_1[\lambda(q_1^H) + (1 - \lambda)(q_1^L)] + [\lambda(r_2^H q_2^H) + (1 - \lambda)(r_2^L q_2^L)]$$

$$= r_1[0.1(1 - 7r_1/6) + 0.9(1/4 - r_1/2)] + [0.1(2r_1^2/9) + 0.9(1/4)(1/8)]$$

$$= [0.1r_1 + 0.9\, r_1/4 - 0.56666r_1^2] + [0.2r_1^2/9 + 0.028125]$$

$$\partial\Pi^A(S)/\partial r_1 = 0.325 - 1.13333r_1 + 0.4r_1/9 = 0\ ;\ r_1 = 0.325/(1.08888) = 0.29847$$

$\Pi^A(S)$ is maximized when $r_1 = 0.29847$ since $\partial^2\Pi^A(S)/\partial r_1^2 = -1.13333 < 0$. However, this is not in the range of r_1, the corner solution is that $r_1 = 3\theta^L/4 = 0.375$

$$\Pi^A(S)|_{r1=0.375} = 0.325(0.375) - 0.5444(0.375)^2 + 0.028125 = \mathbf{0.07344}$$

D.3 If $\theta^L \le r_1 < 3\theta^H/4$

D.3.a If $0.5 \le r_1 < 0.5127$

In this range of r_1, the separating equilibrium is identical to the solution in complete information case (no envy case).

Each type 's solutions are

$q_1^L = 0,\ q_2^L = \theta^L/4 = 1/8$ (since $x^L = 0,\ r_2^L = \theta^L/2 = 1/4$)

$q_1^H = 1 - 7r_1/6,\ q_2^H = r_1/3$

$$\Pi^A(S) = r_1[\lambda(q_1^H) + (1 - \lambda)(q_1^L)] + [\lambda(r_2^H q_2^H) + (1 - \lambda)(r_2^L q_2^L)]$$

$$= r_1[0.1(1 - 7r_1/6) + 0.9(0)] + [0.1(2r_1^2/9) + 0.9(1/4)(1/8)]$$

$$= 0.1r_1 - 0.1(7)\, r_1^2/6 + 0.1(2r_1^2/9) + 0.9(1/4)(1/8)$$

$$\partial\Pi^A(S)/\partial r_1 = 0.1 - 0.18889r_1 = 0\ ;\ r_1 = 0.1/(0.18889) = 0.5294$$

$\Pi^A(S)$ is maximized when $r_1 = 0.5294$ since $\partial^2\Pi^A(S)/\partial r_1^2 = -\ 0.18889 < 0$. However, this is not in the range of r_1, the corner solution is that $r_1 = 0.5127$

$$\Pi^A(S) = 0.1(0.5127) - 0.1(7)(0.5127)^2/6 + 0.1(2(0.5127)^2/9) + 0.9(1/4)(1/8)$$

$$= \mathbf{0.05438}$$

D.3.b If $0.5127 \le r_1 < 0.75$

In this range of r_1, there is no separating equilibrium.

D.4 If $3\theta^H/4 \le r_1$

In this range of r_1, the separating equilibrium is in no envy case.

$q_1^L = 0$, $q_2^L = \theta^L/4 = 1/8$ (since $x^L = 0$, $r_2^L = \theta^L/2 = 1/4$)

$q_1^H = (\theta^H - r_1)/2 = (1 - r_1)/2$, $q_2^H = \theta^H/4 = 1/4$ (since $x^H = 0$, $r_2^H = \theta^H/2 = 1/2$)

$$\Pi^A(S) = r_1[\lambda(q_1^H) + (1 - \lambda)(q_1^L)] + [\lambda(r_2^H q_2^H) + (1 - \lambda)(r_2^L q_2^L)]$$

$$= r_1[0.1(1/2 - r_1/2) + 0.9(0)] + [0.1(1/2)(1/4) + 0.9(1/4)(1/8)]$$

$$= 0.05r_1 - 0.05r_1^2 + 0.1(1/8) + 0.9(1/32)$$

$$\partial\Pi^A(S)/\partial r_1 = 0.05 - 0.1r_1 = 0\ ;\ r_1 = 0.05/(0.1) = 0.5$$

$\Pi^A(S)$ is maximized when $r_1 = 0.5$ since $\partial^2\Pi^A(S)/\partial r_1^2 = -\ 0.1 < 0$. However, this is not in the range of r_1, the corner solution is that $r_1 = 0.75$

$$\Pi^A(S) = 0.05(0.75) - 0.05(0.75)^2 + 0.1/8 + 0.9(1/4)(1/8) = 0$$